AN EXPERIMENTAL STUDY OF NASALITY WITH PARTICULAR REFERENCE TO BRAZILIAN PORTUGUESE

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Kāṃsya-dhvani-samaṃ raṅgaṃ hṛdayad utthitaṃ
bhavet yathā saurāṣṭrikā nārī takra ity
abhibhāṣate evaṃ raṅgāḥ prayoktavyāḥ...

The nasal colour should arise from the heart, with a sound like that of bells: just as the milkmaids of Surastra cry 'takrãããããã' (buttermilk), so should the nasality be realized.

Sarvasaṃmata-Śikṣā 48
Ed. and trsl. A.O. Franke
Göttingen - 1886

Phonetics in Ancient India
by W. S. Allen, p. 40
Oxford University Press
1953

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Luiz Carlos Cagliari
Edinburgh
Christmas, 1977

A B S T R A C T

The anatomy and physiology of the velopharyngeal mechanism is described, focusing the role of the cavities in the production of speech. The velopharyngeal mechanism function during speech is studied at length and an articulatory function to the velum is suggested.

Nasality is characterized in a number of aspects. Various processes responsible for the production of nasality are surveyed, with particular reference to the production of auditory nasality without the participation of the nasal cavities. Quantitative measures of nasality are also discussed.

A review of the most important experimental techniques to study nasality is presented, with the most significant results obtained so far.

A general acoustic characterization of nasality is outlined and specific attention is given to the acoustic properties of the sinuses and the oral and nasal ports. A study of the perceptual features of nasality is presented with emphasis on the problem of vocalic quality changes due to nasalization.

Several experiments on the acoustics, the aerodynamics, the perception and the linguistic value of nasality are reported, including fluorographic, pneumotachographic, electrokymographic, laryngographic, spectrographic and palatographic investigations with phonetic material from Brazilian Portuguese.

An outline of Brazilian Portuguese phonology and phonetics is given with an extensive and detailed phonetic analysis of the phenomenon of nasality in that language. Specific phonological comments about nasalization in Brazilian Portuguese are also presented.

CONTENTS

INTRODUCTION

The aim of the present thesis is to study the phenomena of nasality in a variety of aspects; for example, the nasality which characterizes the nasal consonants and nasalized segments in languages, and the nasality which gives a particular type of voice quality to the speech of certain individuals or linguistic groups. The lack of required nasality, i.e., denasalization, is also discussed.

The thesis is a phonetic study of nasality from different perspectives. The incorporation of different approaches was felt necessary in order to achieve a better understanding about how nasality can be produced and to give a more comprehensive analysis of this phenomenon.

Examples from Brazilian Portuguese have been used to illustrate some aspects of the general discussion about nasality and to provide phonetic material for the experiments reported in the present thesis. But a more detailed account of the occurrence of nasality in that language is also given.

The thesis starts with an outline of Brazilian Portuguese phonetics and phonology, with particular consideration being given to the linguistic analysis of nasality in that language.

The second part of the thesis is concerned with the study of the anatomy and physiology of the velopharyngeal structures involved in the production of nasality.

The third part of the thesis goes into an extensive discussion of the production and perception of nasality. From this discussion, we will conclude that it is necessary to attribute an articulatory function to the velum. Other aspects, such as oral:nasal ratios, aerodynamic characteristics and the notion of a cul-de-sac resonator are also discussed.

In the fourth part of the thesis, the most important techniques of studying nasality are reviewed historically.

The fifth part of the thesis concentrates on a comprehensive investigation of the acoustic characteristics of nasality. Some theoretical points are supported by evidence from experiments carried out by the author. Perceptual features of nasality are also studied.

In the sixth and last part of the thesis, a series of experiments carried out by the author is reported. They include aerodynamic, fluorographic, pneumotachographic and electrokymographic investigations.

It is hoped that this thesis will provide a better understanding of the complex mechanism producing nasality, a new insight into the articulatory function of the velum and some contribution to the acoustic and perceptual studies of nasality. In addition to that, it is hoped that the discussion of nasality in Brazilian Portuguese will provide useful information about how the phenomenon is exploited for linguistic purposes in a particular language.

PART I : NASALITY IN BRAZILIAN PORTUGUESE

Chapter 1 : Outline of Brazilian Portuguese

1.1. Introduction

The Portuguese language, as spoken in Brazil, differs from European Portuguese in a variety of aspects. Portuguese is the official language of Brazil, with approximately 110,000,000 speakers. Although the Portuguese language in Brazil shows remarkable uniformity, some regional linguistic variation allows a subdivision of Brazilian Portuguese into dialects.

The present work refers in particular to one of the Brazilian dialects, called Paulista dialect. Paulista dialect is the dialect of Portuguese spoken typically by the majority of people who live in the state of São Paulo. The dialect is thus spoken by a large number of Brazilians, since the state of São Paulo is one of the most populated states of Brazil. In the state of São Paulo there is another minority dialect, the Caipira dialect, which is not investigated in the present work.

One of the aims of the present work is to study the manifestation of nasality in Brazilian Portuguese (herein abbreviated BP), with special focus on Paulista dialect. It is, therefore, convenient to start by making a summary statement of the phonological structure of the language. This statement outlines only those aspects of the language required to facilitate the more detailed discussion of nasality as it relates in particular to BP.

1.2. Syllable Structure

In BP, a syllable can be stressed or unstressed. Stress in BP has the value of a suprasegmental phoneme (Strevens 1954: 26;

M.Câmara 1970: 52-55, and 1971: 35-39; Pontes 1972: 19).

The structure of the syllable in BP can be represented by the following formula:

$$C_{0-2} \quad V \quad C_{0-2}$$

where C represents a consonant phoneme and V a vowel phoneme. The subscript figures indicate the number of C elements tha~~y~~t may occur preceding or following V. Thus C_{0-2} means that there may be zero, one or two C elements before or after V. Examples of all permissible syllable patterns are given in section 1.7. of the present chapter.

1.3. <u>Nasal Archiphoneme: /N/</u>

A nasal archiphoneme /N/ is posited whose exponents may optionally be as follows:

i) nasalization of the preceding vowel, with no accompanying nasal;

Examples:

/ˈpoiN/	[ˈpõĩ] (*)	(put)
/ˈmaNʃa/	[ˈmɜ̃ʃa]	(stain)
/ˈmaNta/	[ˈmɜ̃ta]	(blanket)

This realisation may occur for any occurrence of /N/.

ii) optional nasalization of the preceding vowel, with an accompanying nasal. The specific nature of the nasal is also optionally conditioned either by the preceding vowel or by a following stop within words. The realisation of the nasal, when

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(*) The symbols used in transcriptions throughout this thesis are those of the IPA alphabet. When citing from the literature, however, the original terminology and phonetic transcription of the author concerned is retained.

conditioned by the preceding vowel, is as follows:

a) a palatal nasal - following a front vowel;

b) a velar nasal - following a non-front vowel.

On the other hand, when the nasal is conditioned by a following stop within words, it will have the same place of articulation as the stop, i.e., it will be a homorganic nasal.

Examples:

/'fiNka/	['fĩɲka]	['fiɲka]	['fĩɲka]	(drive in)
/'fuNdu/	['fũŋdo]	['fuŋdo]	['fũndo]	(deep)
/'koNʃa/	['kõŋʃa]	['koŋʃa]		(shell)

1.4. <u>Vowel Phonemes</u>

The vowel phonemes in the BP vowel system may be monophthongs, diphthongs or triphthongs. A diphthong is transcribed in this thesis by the use of a digraph symbol, e.g., /ai/, as in /'kais/ <u>cais</u> (quay); similarly, a triphthong is transcribed using a 'trigraph' symbol, e.g., /uai/, as in /'kuais/ <u>quais</u> (which - pl.).

1.4.1. Monophthongs:

a) In stressed syllables: all monophthongs may occur in stressed syllables.

Examples:

/ i /	/'xima/	['xima]	(rhyme)
/ e /	/'xema/	['xema]	(row)
/ a /	/'xama/	['xɜma]	(boughs)
/ o /	/'xoma/	['xoma]	(Rome)
/ u /	/'xuma/	['xuma]	(head for)
/ ɛ /	/'bɛla/	['bɛla]	(beautiful)
/ ɔ /	/'bɔla/	['bɔla]	(ball)

b) In unstressed syllables: all monophthongs may occur in unstressed syllables, but the monophthongs /ɛ, ɔ/ may occur unstressed only in compound words.

Examples:

/ i /	/ilu'zauN/	[ilu'zʌ̃ʊ̃]	(illusion)
/ a /	/alu'zauN/	[alu'zʌ̃ʊ̃]	(allusion)
/ e /	/e'taria/	[e'taɾɪa]	(of age)
/ o /	/o'taria/	[o'taɾɪa]	(credulous)
/ u /	/u'rina/	[u'ɾina]	(urine)
/ a /	/a'rena/	[a'ɾena]	(arena)
/ ɛ /	/kafɛ'ziɲu/	[kafɛ'zĩɲʊ]	(coffee)
/ ɔ /	/sɔ'meNti/	[sɔ'mẽnti]	(only)

1.4.2. Diphthongs:

A diphthong may occur in stressed or unstressed syllables. The diphthongs form three classes according to the nature of their diphthongal movements. The three classes are labeled here V_i, V_u and ${}_uV$.

V_i and V_u are falling diphthongs, where the beginning part of the diphthongal movement is more prominent than the final part; ${}_uV$ is the class of rising diphthongs, where the final part of the diphthongal movement is more prominent than the beginning part: the diphthongs of this class are always preceded by a velar stop.

a) Diphthongs of the class V_i:

/ ei /	/'xeis/	['xeis]	(kings)
/ ɛi /	/'xɛis/	['xɛɪs]	(cents)
/ ai /	/'pai/	['paɪ]	(father)
/ ɔi /	/'dɔi/	['dɔɪ]	(it hurts)
/ oi /	/'boi/	['boɪ]	(bull)
/ ui /	/'fui/	['fuɪ]	(I went)

b) Diphthongs of the class V_u:

/ iu /	/'viu/	['viɷ]	(he saw)
/ eu /	/'seu/	['seɷ]	(yours)
/ ɛu /	/'sɛu/	['sɛɷ]	(sky)
/ au /	/'sau/	['sɑɷ]	(salt)
/ ɔu /	/'sɔu/	['sɔɷ]	(sun)
/ ou /	/'sou/	['soɷ]	(I am)
/ uu /	/'suu/	['suɷ]	(south)

c) Diphthongs of the class $_uV$:

/ ui /	/'likuidu/	['likɷidɷ]	(liquid)
/ ue /	/e'kuevu/	[e'kɷevɷ]	(of the same age)
/ uɛ /	/e'kuɛstri/	[e'kɷɛstrɩ]	(equestrian)
/ ua /	/kuali'dadi/	[kɷali'dadɩ]	(quality)

1.4.3. Triphthongs:

The triphthongs occur almost exclusively in stressed syllables. only two examples of triphthongs have been found in unstressed syllables:

/ uai /	/kais'kɛx/	[kɷaɩs'kɛr̥]	(any - pl.)
/ uau /	/kuau'kɛx/	[kɷɑɷ'kɛr̥]	(any - s.)

The triphthongs have the more prominent part at the centre of the movement and the beginning and ending parts are less prominent. All triphthongs have the same type of beginning, with the movement assuming divergent directions afterwards. The triphthongs are always preceded by a velar stop /k/ or /g/.

a) Triphthongs of the class $_uV_i$:

/ uei /	/averi'guei/	[averi'gɷeɩ]	(I examined)
/ uai /	/'kuais/	['kɷaɩs]	(which - pl.)
/ uoi /	/sa'guoiNs/	[sa'gɷõɩ̃s]	(lobbies)

b) Triphthongs of the class $_{u}V_{u}$:

/ uau /	/'kuau/	['kɒɑɒ]	(which - s.)
/ uiu /	/deliN'kuiu/	[delĩŋ'kɒiɒ]	(he offended)
/ uou /	/averi'guou/	[aveɾi'gɒoɒ]	(he examined)

1.4.4. Review of literature:

The phonological treatment of phonetic diphthongs is one of the most controversial areas of the language; compare, for example: Reed and Leite (1947: 200-201), Wise (1957), Dahl (1964: 317), Feldman (1967: 53-54), M.Câmara (1970: 46). The diphthongs of Portuguese have been interpreted by some writers as formed by a vowel plus a semivowel. For example, Head defines a diphthong as follows:

> "The present study would define the Portuguese diphthongs as clusters of a syllabic vowel and a non-syllabic phonetic semivowel within the same syllable nucleus" (Head 1964: 216).

It is not rare to find analyses of Portuguese where phonetic diphthongs and triphthongs are treated phonologically as a complex made up of a V element (representing the most prominent part of the diphthong or triphthong) and a consonantal element (/j/ or /w/), preceding and/or following the V element. Consequently, such analyses produce alternative statements of syllable structure and different rules for the distribution of the consonants and vowel phonemes in syllables, from the one presented in this thesis.

1.5. Consonant Phonemes

The consonant system of BP incorporates the following phonemes:

/p, b, t, d, k, g, f, v, s, z, ʃ, ʒ, x, r, l, ʎ, m, n, ɲ /.
They are in phonemic opposition in the language, as one can see in the following examples:

/ p /	/'pata/	['pata]	(paw)

/ b /	/'bata/	['bata]	(beat)
/ t /	/'kata/	['kata]	(pick out)
/ d /	/'kada/	['kada]	(each)
/ k /	/'kata/	['kata]	(pick out)
/ g /	/'gata/	['gata]	(cat)
/ f /	/'faka/	['faka]	(knife)
/ v /	/'vaka/	['vaka]	(cow)
/ s /	/'kasa/	['kasa]	(hunting)
/ z /	/'kaza/	['kaza]	(house)
/ ʃ /	/'ʃa/	['ʃa]	(tea)
/ ʒ /	/'ʒa/	['ʒa]	(already)
/ x /	/'naxa/	['naxa]	(he tells)
/ r /	/'nara/	['naɾa]	(a name)
/ l /	/'mala/	['mala]	(suitcase)
/ ʎ /	/'maʎa/	['maʎa]	(sweater)
/ m /	/'somu/	['somo]	(I sum)
/ n /	/'sonu/	['sono]	(sleep)
/ ɲ /	/'soɲu/	['sõɲo]	(dream)

1.6. <u>Distribution of Consonants in Syllable Structure</u>

1.6.1. C preceding V:

In syllables with structure CV-, C may be any consonant. But /r/ does not occur in word initial position, and the phonemes / ʎ, ɲ /, in the same context, occur in only a few words.

In syllables with the structure CCV- (with CC referred to here as C_1 and C_2), C_2 will be either /r/ or /l/. When C_2 is /r/, C_1 may be any stop or the labiodental fricatives /f, v/; when C_2 is /l/, C_1 is any stop, except /d/, or the labiodental fricative /f/. We could represent all these statements schematically as follows:

C_1	C_2	V
p, b, t, d, k, g, f, v	r	V
p, b, t, k, g, f	l	V

1.6.2. C following V:

In -VC syllables, C will be one of the following: /s, x, N/, as shown schematically below:

V	C
V	s, x, N

In syllables with the structure -VCC (with CC referred to here as C_3 and C_4), C_3 may be either /x/ or /N/, and C_4 will always be /s/. The cluster /xs/, however, occurs only in few words. This is shown schematically below:

V	C_3	C_4
V	x, N	s

1.7. Illustration of Possible Syllable Patterns in BP

The following examples illustrate the different syllable patterns of BP. All cases of V are represented.

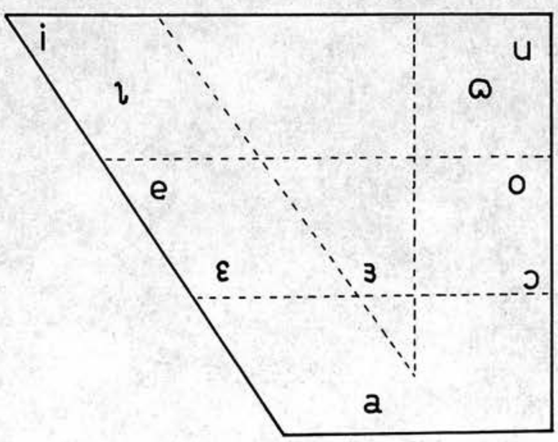
V	/'ε/	['ε]	(is)
	/'eu/	['eo]	(I)
C V	/'pε/	['pε]	(foot)
	/'teu/	['teo]	(yours)
	/'kuau/	['koao]	(which - s.)

C C V	/'kru/	['kɾu]	(raw)
	/'kreu/	['kɾeʊ]	(believed)
V C	/'ɛs/	['ɛs]	(are)
	/'eis/	['eɩs]	(here is)
V C C	/xu'iNs/	[xu'ĩɲ̃s]	(wicked)
	/le'oiNs/	[le'õĩɲ̃s]	(lions)
C V C	/'pɛs/	['pɛs]	(feet)
	/'teus/	['teʊs]	(yours)
	/'kuais/	['kʊaɩs]	(which - pl.)
C V C C	/pexspeki'tiva/	[peɾ̥speкɩ'tiva]	(perspective)
	/'maiNs/	['mɜ̃ĩɲ̃s]	(mothers)
	/sa'guoiNs/	[sa'gʊõĩɲ̃s]	(lobbies)
C C V C	/'plastiku/	['plastikʊ]	(plastic)
	/uN'brais/	['ũm'bɾaɩs]	(doorpost)
C C V C C	/'treNs/	['tɾẽɲ̃s]	(trains)
	/kɔ'broiNs/	[kɔ'bɾõĩɲ̃s]	(big snakes)

1.8. The Phonetic Specification of BP Vowel Phonemes

1.8.1. Monophthongs:

a) The quality of certain exponents of the monophthongs /i, e, ɛ, a, ɔ, o, u/ is specified on the cardinal-vowel diagram given below. The exponents [ɩ] and [ʊ] are discussed in (b) below.



b) Optional weakening rule:

The monophthongs /i, e/ and /o, u/ may have the exponents [ɪ] and [ʊ] respectively, when unstressed. This happens more typically in some words than in others, and it is always an optional rule in Paulista dialect. The weakening is, however, very common in unstressed wordfinal syllables. When this rule is applied, the opposition between /i/ and /e/ or between /o/ and /u/ is neutralized. See cardinal-vowel diagram above and Part I, Chapter 2, Section 2.2.2. (c).

Examples:

/kuali'dadi/	[kʊali'dadɪ] ,	[kʊalɪ'dadɪ]	(quality)
/'sixkulu/	['sir̥kulʊ] ,	['sir̥kʊlʊ]	(circle)
/e'lena/	[e'lena] ,	[ɪ'lena]	(Helen)
/'pɛrola/	['pɛɾola] ,	['pɛɾʊla]	(pearl)

c) The monophthong /a/ :

The monophthong /a/ has an exponent [ɜ] under the following conditions:

i) before /N/

ii) when stressed and followed immediately by a nasal in the beginning of the next syllable in words. It may also have, optionally, an exponent [ɜ] when unstressed and followed immediately by a nasal in the beginning of the next syllable in words.

The same monophthong /a/ has an exponent [a] elsewhere.

Examples:

/ix'maN/	[ir̥'mɜŋ]		(sister)
/'kama/	['kɜma]		(bed)
/ka'miɲa/	[ka'mĩɲa] ,	[kɜ'mĩɲa]	(he walks)
/ka'lada/	[ka'lada]		(quiet)

d) Whispered vowels:

The phonetic exponents of the phonemes /i, a, u/ may occur whispered [ɩ̥, ḁ, ɷ̥] instead of voiced [ɩ, a, ɷ] occasionally, when before a voiceless segment, and more frequently in wordfinal position before pause.

Examples:

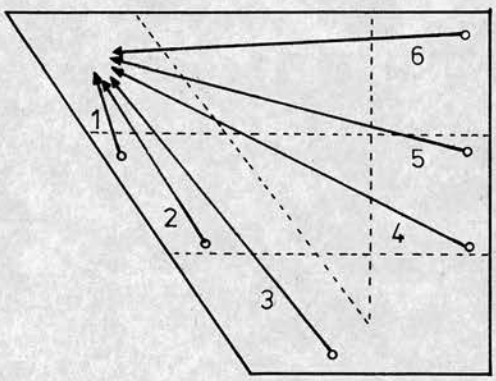
/'kɔxti/	['kɔr̥tɩ],	['kɔr̥tɩ̥]	(the cut)
/'kɔxta/	['kɔr̥ta],	['kɔr̥tḁ]	(he cuts)
/'kɔxtu/	['kɔr̥tɷ],	['kɔr̥tɷ̥]	(I cut)

1.8.2. Diphthongs and triphthongs:

The quality changes involved for the exponents of the diphthongs and triphthongs are specified on the cardinal-vowel diagrams below. Arrows are used to indicate the direction of the change.

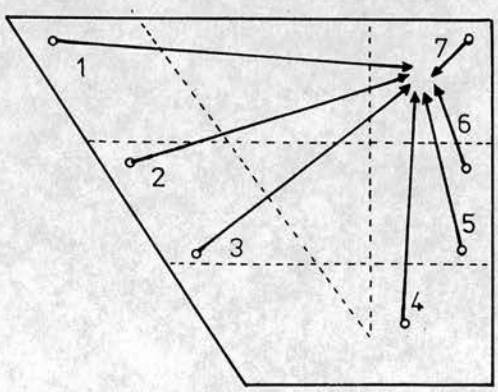
a) Diphthongs of the class V_i :

1. / ei / : [eɩ]
2. / εi / : [εɩ]
3. / ai / : [aɩ]
4. / ɔi / : [ɔɩ]
5. / oi / : [oɩ]
6. / ui / : [uɩ]



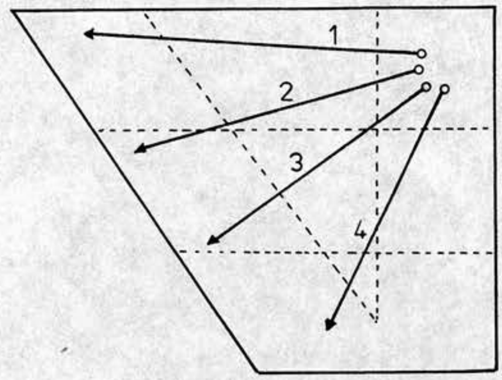
b) Diphthongs of the class V_u

1. / iu / : [iɷ]
2. / eu / : [eɷ]
3. / εu / : [εɷ]
4. / au / : [ɑɷ]
5. / ɔu / : [ɔɷ]
6. / ou / : [oɷ]
7. / uu / : [uɷ]



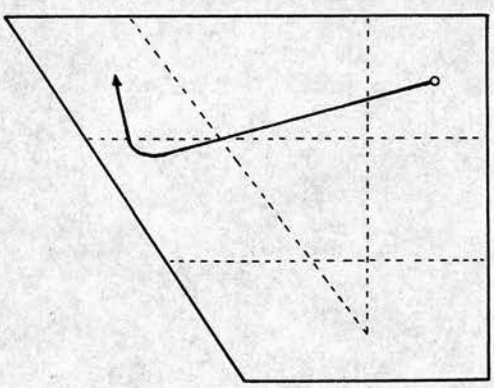
c) Diphthongs of the class $_{u}V$:

1. / ui / : [ʊi]
2. / ue / : [ʊe]
3. / uɛ / : [ʊɛ]
4. / ua / : [ʊa]

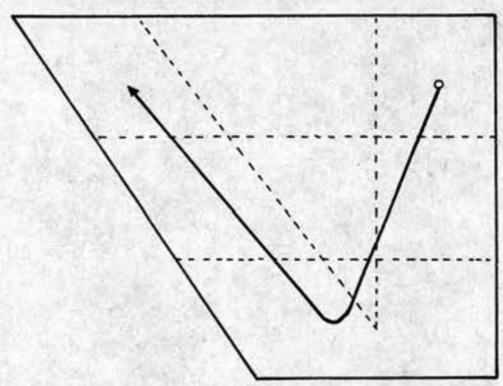


Similarly, phonetic exponents of the triphthongs can be specified as follows:

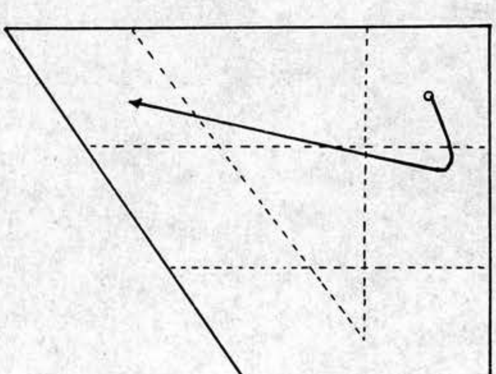
d) Triphthongs of the class $_{u}V_{i}$:



/ uei / : [ʊeɪ]

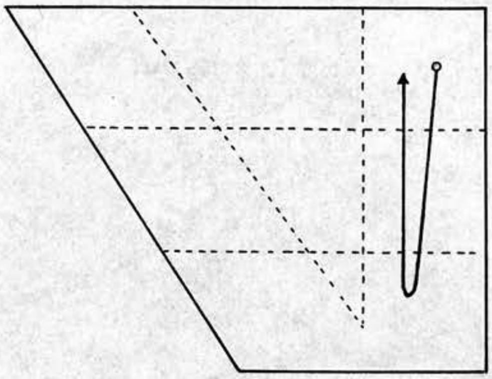


/ uai / : [ʊaɪ]

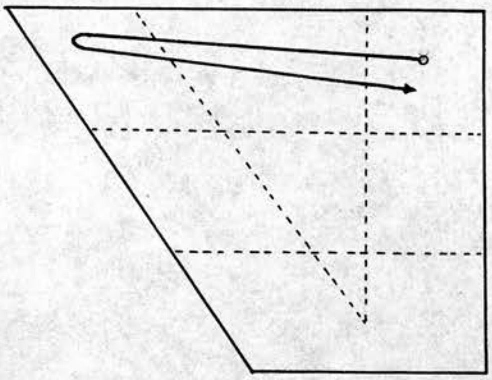


/ uoi / : [ʊoɪ]

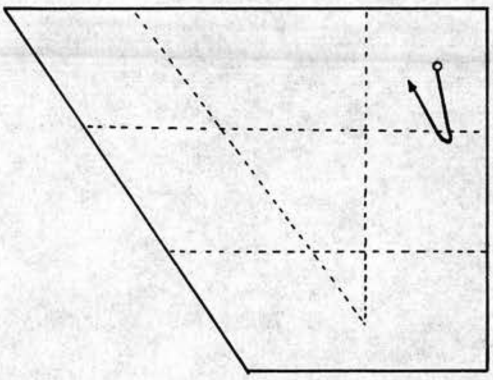
e) Triphthongs of the class $_{u}V_{u}$:



/ uau / : [ɷɑɷ]



/ uiu / : [ɷiɷ]



/ uou / : [ɷoɷ]

1.8.3. Review of literature:

In the literature, it is uncommon to find the phonetic quality of vowels in BP specified. The phonetic quality of them can be inferred mainly from phonetic transcriptions found in publications. Nevertheless, some description of the exponents of some vowels can be found in the following works: Reed and Leite (1947: 197-198), Strevens (1954), Lacerda and Strevens (1956: 9-15), Wise (1957: 513-519), Dahl (1964: 316), Head (1964: 169-183), Feldman (1967: 45-48), M. Câmara (1970: 31-35; 1971: 13-25), Pontes (1972: 17-18, 21-22) and Mioni (1973: 286-295, 307-309).

In particular, the occurrence of whispered vowels (also called voiceless vowels by some authors) in Portuguese, has been observed by the following writers: G.Viana (1892), Sweet (1913), Strevens (1954: 15), M.Câmara (1971: 21), Pontes (1972: 21) and Mioni (1973: 287) among others.

1.9. The Phonetic Specification of BP Consonant Phonemes (*)

1.9.1. Stops:

The phonemes /p, b, t, d, k, g/ are realised as follows:

/ p, b /	:	[p, b]	:	voiceless and voiced bilabial stops.
/ t, d /	:	[t, d]	:	voiceless and voiced denti-alveolar stops.
/ k, g /	:	[k, g]	:	voiceless and voiced velar stops.

See examples in section 1.5. of this chapter.

The velar stops show a strong tendency to have an advanced place of articulation directly proportional to the frontness of the following vowel in the syllable.

Examples:

/'kada/	['kada]	(each)
/'kilu/	['k˖ilo̞]	(kilo)

Aspiration in stops is not a common feature of BP. It is very common, however, outside Paulista dialect, to have affricated exponents [tʃ, dʒ] of the phonemes /t, d/ when followed immediately by a front close vowel.

There is good agreement among writers on BP about stops. Dahl (1964: 314) is the only author to report a postalveolar [c, ɟ]

(*) The exponents listed are limited to those which are required to elucidate in general the phonetic specification of the BP phonemes, and which arise in the phonetic transcriptions in this thesis.

articulation for /t, d/ before /i/, which is according to him, 'currently used in S. Paulo and other parts of Brazil'.

1.9.2. Fricatives:

The phonemes /f, v, z, ʃ, ʒ/ are realized as follows:

/ f, v / : [f, v] : voiceless and voiced labiodental fricatives.

/ ʃ, ʒ / : [ʃ, ʒ] : voiceless and voiced palato-alveolar central fricatives.

/ z / : [z] : voiced alveolar central fricative.

See examples in section 1.5. of this chapter.

The phoneme /s/ has an exponent [z] a voiced alveolar central fricative when it is post-vocalic before a voiced consonant in the following syllable, and in cases of liaison (see Part I, Chapter 2, Section 2.3.). The same phoneme /s/ has an exponent [s] a voiceless alveolar central fricative, elsewhere, i.e., before a vowel within syllables; after a vowel at the end of a syllable, followed by a voiceless consonant or pause; and when not in liaison (see Part I, Chapter 2, Section 2.3.).

Examples:

/'mesma/	['mezma]	(same)
/as 'azas/	[a'zazas]	(the wings)
/'kasa/	['kasa]	(hunting)
/'pasta/	['pasta]	(paste)

It is interesting to note that although the phonemes /s/ and /z/ are in phonemic opposition in syllable initial position (i.e., as C in CV- syllables), the opposition does not exist in syllable final position (i.e., as C in -VC syllables), since /z/ does not occur in that context. However, phonetically, the phoneme /s/ in -VC syllables may have the exponent [s] or [z] conditioned by the context, as described above.

As with stops, the fricatives in question are not the object of controversy in the literature.

1.9.3. Phonemes / r, x / :

The phoneme /r/ is realised as follows:

/ r / : [ɾ] : voiced denti-alveolar tap.

Examples:

/'vara/	['vaɾa]	(stick)
/'koru/	['koɾʊ]	(choir)

The phoneme /x/ has several alternative exponents in Paulista dialect:

a) /x/ is currently realised as [x, ɣ], voiceless or voiced velar fricative, in syllable initial position (i.e., as C in CV- syllables)

b) when /x/ occurs word finally before pause it is realised mainly as [ɹ̥] a voiceless denti-alveolar central fricative;

c) The phoneme /x/ is realised as [ɾ] a voiced denti-alveolar tap, in cases of liaison (see Part I, Chapter 2, Section 2.3.);

d) In all other postvocalic positions, the phoneme /x/ is realised variously as [r̥, r] voiceless or voiced alveolar trill, or [ɹ̥].

Examples:

/'baxa/	['baxa],	['baɣa]	(ingot)
/'max/	['maɹ̥]		(sea)
/'max autu/	['ma'ɾaʊtʊ]		(high seas)
/'kaxta/	['kar̥ta],	['kaɹ̥ta]	(letter)
/'baxba/	['barba],	['baɹ̥ba]	(beard)

For the speakers of Paulista dialect in some areas, the phoneme /x/ may also have an exponent [ɽ] a voiced retroflex approximant, in syllable final position (i.e., as C in -VC syllables). This approximant can however be produced as a 'molar-R', as described by Uldall (1958), rather than as a retroflex sound with the tip of the tongue curled back in the mouth.

Examples:

/'kaxta/	['kar̥ta]	['kaɽta]	(letter)
/'baxba/	['barba]	['baɽba]	(beard)

The phoneme /x/ is in opposition to /r/ only in intervocalic position medially in words.

Examples:

/'kaxu/	['kaxo]	(car)
/'karu/	['karo]	(dear)
/'gɛuxa/	['gɛoxa]	(gill of fish)
/'mauru/	['maoro]	(a name)

In the literature, the discussion of the exponents of the phoneme /x/ is confusing. Compare, for example, the following works: Reed and Leite (1947), Wise (1957), Dahl (1964), Feldman (1967), M.Câmara (1970), Pontes (1972), Mioni (1973) and Brakel (1974).

1.9.4. Laterals:

The phonemes / l, ʎ / have the following phonetic exponents:

/ l / : [l] : voiced denti-alveolar lateral

/ ʎ/ : [ʎ] : voiced palatal lateral

See examples in section 1.5. of this chapter.

In the literature, the discussion of the exponents of the lateral phonemes is also confusing. Compare, for example, the following works: Reed and Leite (1947: 196), Wise (1957: 525-526), Dahl (1964: 315), Feldman (1967: 52), M.Câmara (1971: 17), Mioni

(1973: 282-283) and Pontes (1972).

1.9.5. Nasals:

There are three nasal phonemes in BP: / m, n, ɲ /. They occur only in syllable initial position and they have the following exponents:

/ m / : [m] : voiced bilabial nasal

/ n / : [n] : voiced dentialveolar nasal

/ ɲ / : [ɲ] : voiced palatal nasal

See examples in section 1.5. of this chapter.

The occurrence of / ɲ / in word initial position is practically restricted to a few words.

Reed and Leite (1947: 196) and Head (1964: 156) interpreted [n] as an alveolar articulation. Wise (1957: 525) interpreted it as dental, and Pontes (1972: 20) attributed an alveopalatal place of articulation to [ɲ]. Hall (1943: 5) presented two variants in free variation, as follows:

/ ɲ / : [ñ] : dental nasal with palatal yod release

[ɲ] : palatal nasal with palatal yod release

Pontes draws attention to the fact that the process of devoicing segments such as vocoids can also affect voiced contoids preceding the devoiced vocoids, the whole syllable becoming then voiceless. According to her, this process affects the nasals too, and it may happens in words like <u>cama</u> (bed) and <u>cana</u> (sugar cane).

Chapter 2 : The Phonetics of Nasality in Brazilian Portuguese

2.1. Introduction

Discussion of the phonetic specification of nasality in BP, largely omitted from chapter 1, will be considered in more detail in the present chapter.

Portuguese nasality has been compared with French nasality by G. Viana (1892), Sweet (1913), Heffner (1950: 13) and Delattre (1969a, 1969b); all these writers claimed that Portuguese nasality is less strong than French nasality. G. Viana explaining the difference between the two languages, states that:

> "Nasality may accompany the emission of the vowel without being carried over it: Portuguese nasal vowels from the South are of this type, ã, ẽ, õ, etc., and the appropriate diacritic is the tilde (˜); they are also called 'nasal vowels of first degree'. However, this sort of nasality may accompany them, and it can be extended over them by gutturalization: these are the 'nasal vowels of second degree', which are heard, for instance, in the North: $\overset{\backsim}{a}$, $\overset{\backsim}{e}$, $\overset{\backsim}{o}$, and whose diacritic may be a reverse tilde; their acoustic effect reminds of the diphthongs, and therefore $\overset{\backsim}{a}$ is almost $\overset{\backsim}{a}\overset{\backsim}{u}$, $\overset{\backsim}{e}$ is almost $\overset{\backsim}{e}\overset{\backsim}{i}$. The French nasal vowels are of this type, principally those from the North" (G.Viana 1892: 14-15 - the translation is mine; see Appendix 1 (a)).

Strevens (1954), in a study of European Portuguese, also observed two degrees of nasalization. According to him, the stronger degree of nasalization (which he refers to as 'the second degree') characterizes vocalic nasalization which is significant phonologically, and the less strong degree occurs when nasalization is not significant phonologically. On the second degree of nasalization, he comments:

> "The second degree of nasal resonance is very much stronger: in order to produce a sound of this type in a manner acceptable to the informant I have to produce the maximum nasality of which I am capable for a given loudness. Presumably the soft palate is lowered to the maximum extent" (Strevens 1954: 15-16).

Strevens carried out further investigations of Portuguese, and in an article with Lacerda, they expressed the same point of view about the two degrees of nasalization in Portuguese. They say:

> "The existence of two different degrees of nasality is confirmed. The stronger degree corresponds to the nasal vowels and the weaker degree to the nasalized vowels" (Lacerda and Strevens 1956: 16)

Lacerda and Rossi (1958) compared the degree of nasalization of Lisbon speech with the degree of nasalization of Rio de Janeiro speech, and they came to the conclusion that BP nasalization is stronger than nasalization in European Portuguese. Mioni (1973: 310) in a comparative study of European Portuguese and BP, claimed that the nasalization of a vowel followed by a nasal in the beginning of the next syllable in words, is stronger in BP than in European Portuguese. Head (1964) used an acoustic criterion to evaluate the different degrees of nasalization in European and Brazilian Portuguese. He states:

> "That the degree of nasality in Cariocan nasal vowels and diphthongs is stronger than in the corresponding nasal sounds in Lisbon speech is verified by the relative darkness of the nasal formants" (Head 1964: 205).

In spite of the fact that nasality is characterized by a severe damping of the spectrum of the corresponding oral vowel, the relative darkness of the formants on the spectrograms is not consistently related to different degrees of perceived nasality. This question will be considered in detail later (see Part V).

The identification of perceptually different degrees of nasality is a quite difficult task to do because of the entanglement of it with other factors in producing speech. Nasality influences the basic acoustic structure of vowels and consonants differently, and yet different types of vowels are themselves influenced differently by nasalization, as we will discuss later (see Part V). Moreover, there is evidence that the auditory effect of nasalization can be modified by the co-occurrence of other factors such as stress (Potter et al. 1947: 166), certain types of phonation like whisper, etc. Therefore, when nasality is superimposed on speech segments, the auditory effect is not unique for all segments, though they may all convey some sort of quality that one wishes to identify as nasality (see Part III, Chapter 5). The non-phonological existence of different degrees of nasality (conditioned by the context) or of different types of nasality (see Part III, Chapter 2), still needs further investigation. Investigation is particularly difficult in this area, as we will see later (Part III, Chapters 2 and 4), mainly because of the difficulty of establishing a reliable and operative criterion for assessing different degrees or types of nasality.

Lacerda and Rossi (1958) in a study using the chronograph, discussed vocalic nasalization, and made the point that in BP, the onset of nasal resonance coincides with the beginning of the articulation of the vowel, while in European Portuguese a nasalized vowel has an oral onset, becoming nasalized later. Clumeck using the nasograph, reports:

"The American English and some of the (Brazilian)

Portuguese data show the onset of nasalization preceding the onset of the vowel" (Clumeck 1976: 344).

Another point related to the distribution of nasality over segments is concerned with the traditional statement (see, for example, M. Câmara 1970: 32) that there is no nasalized hiatus, i.e., nasalization does not spead over two contiguous vowels. The term 'hiatus' is used normally to mean a break shorter than a normal pause (Pike 1947: 239). But, in the present description of Portuguese, the term 'hiatus' is used with the meaning that it has in the phonetic tradition of Portuguese, i.e., it means the presence of a syllable boundary dividing two contiguous vowels. In fact, it is typical of a hiatus to break the process of nasalization over two contiguous vowels, as shown by the following examples:

/ku'aNdu/	[kʊ'ɜ̃ndʊ]	(straining)
/'baɲa/	['bɜ̃ĩa]	(fat)

Further discussion about the occurrence of nasality in vowels in BP will be given in the next sections of this chapter and in Part VI, Chapter 5.

2.2. Nasalization of Vowels in Brazilian Portuguese

2.2.1. Sources of vowel nasalization:

In the analysis of BP presented in this thesis, the nasalization of vowels has two principal sources:

i) A vowel will always have a nasalized exponent when followed by /N/ , provided /N/ is not also realized as a nasal;

ii) A vowel will be optionally nasalized, either when followed by /N/ , where /N/ has a nasal exponent, or when the vowel is followed by a nasal phoneme in the following syllable within words.

These rules apply to all vowels, monophthongs, diphthongs and triphthongs.

Examples:

	(i)	(ii)		
/ˈpauN/	[ˈp3̃õ]			(bread)
/ˈveN/		[ˈvẽɲ]	[ˈveɲ]	(he comes)
/ˈveɲa/		[ˈvẽɲa]	[ˈveɲa]	(come)
/ˈmaiN/	[ˈm3̃ĩ]	[ˈm3̃ĩɲ]	[ˈm3ɩɲ]	(mother

It should be pointed out that any vowel following a nasal consonant may also be fully or partially nasalized. Investigations with pneumotachographic recordings carried out by the author indicate that complete interruption of nasal airflow by the velum takes place normally at the end of the articulation of the vowel which follows the nasal consonant (see Part VI, Chapter 5).

2.2.2. Monophthongs:

a) In BP, all monophthongs, except /ɛ / and /ɔ /, can occur before the nasal archiphoneme; and all monophthongs can occur before a nasal phoneme. Nasalized exponents of the monophthongs are given below with examples.

i) Monophthongs which may occur before /N/ :

/ i /	:	[ĩ]	/ˈsiN/	[ˈsĩɲ]	(yes)
/ e /	:	[ẽ]	/ˈseN/	[ˈsẽɲ]	(without)
/ a /	:	[3̃]	/ˈsaN/	[ˈs3̃ŋ]	(healthy)
/ o /	:	[õ]	/ˈsoN/	[ˈsõŋ]	(sound)
/ u /	:	[ũ]	/ˈxuN/	[ˈxũŋ]	(rum)

ii) Monophthongs which may occur before a nasal phoneme:

/ i /	:	[i, ĩ]	/ˈsinu/	[ˈsinɷ], [ˈsĩnɷ]	(bell)
/ e /	:	[e, ẽ]	/ˈlem^{i}/	[ˈlemɩ], [ˈlẽmɩ]	(helm)

/ ɛ /	:	[ɛ, ɛ̃]	/'trɛmi/	['trɛmɩ],	['trɛ̃mɩ]	(he trembles)
/ a /	:	[ɜ, ɜ̃]	/'baɲa/	['bɜɲa],	['bɜ̃ɲa]	(fat)
/ ɔ /	:	[ɔ, ɔ̃]	/'ɔmeN/	['ɔmẽɲ],	['ɔ̃mẽɲ]	(man)
/ o /	:	[o, õ]	/'sonu/	['sono],	['sõno]	(sleep)
/ u /	:	[u, ũ]	/'fumu/	['fumo],	['fũmo]	(smoke)

b) As we said earlier, the phonemes /ɛ / and /ɔ / never occur before /N/ in BP. Their occurrence before a nasal consonant is very restricted; in Paulista dialect, they may occur only before /m/. In addition, they occur only in a few words, or they may appear sporadically in the speech of some individuals in words which, for other speakers, do not contain either /ɛ / or /ɔ / . In my own pronunciation (Paulista dialect), words like <u>creme</u> (cream) and <u>treme</u> (he trembles), or <u>como</u> (I eat) and <u>come</u> (he eats), have the phonemes /e/ : /ɛ / and / o / : /ɔ / in opposition in the first syllable. Their corresponding exponents may or may not be nasalized, according to the rules for the nasalization of vowels given earlier (see Section 2.2.1.).

Examples:

/'kremi/	['kremɩ],	['krẽmɩ]	(cream)
/'trɛmi/	['trɛmɩ],	['trɛ̃mɩ]	(he trembles)
/'komu/	['komo],	['kõmo]	(I eat)
/'kɔmi/	['kɔmɩ],	['kɔ̃mɩ]	(he eats)

In other dialects, the opposition between /e/ and /ɛ / or /o/ and /ɔ / is often neutralized in this context in favour of the phonemes / e / and / o /, and consequently, those dialects cannot have nasalized exponents [ɛ̃] and [ɔ̃] .

c) Earlier in section 1.8.1. (b), an optional weakening rule was given involving the neutralization of the opposition between /i/ and /e/, and between /u/ and /o/ in unstressed syllables. This rule applies equally when /i, e/ or /u, o/ occur in unstressed syllables before /N/, except when wordfinal. Thus, with neutralization in this particular context, /i, e/ and /u, o/ are realized as [ĩ] and [õ] respectively. In wordfinal position, such neutralization before /N/ does not occur

Examples:

/i, e/ :	[ĩ]	/iNsta'lax/	[ĩsta'laɾ̥]	(to install)
		/eNse'ada/	[ĩsɪ'ada]	(cove)
/u, o/ :	[õ]	/kuN'prida/	[kõm'pɾida]	(accomplished)
		/koN'prida/	[kõm'pɾida]	(long)

d) In unstressed wordfinal position, only three monophthongs may occur when not followed by /N/ : /i, a, u/. In the same environment, but preceding /N/, five monophthongs may occur: /i, e, a, o, u/.

Examples:

/ i / :	[ĩ]	/'iNteriN/	['ĩnteɾĩɲ]	(interim)
/ e / :	[ẽ]	/'ʒɔveN/	['ʒɔvẽɲ]	(young)
/ a / :	[ɜ̃]	/'ɔxfa /	['ɔɾ̥fɜ̃ŋ]	(orphan)
/ o / :	[õ]	/'sɔloN/	['sɔlõŋ]	(a name)
/ u / :	[ũ]	/'aubuN/	['ɑʊbũŋ]	(album)

e) Certain monophthongs may be realized as phonetic diphthongs, which may be optionally nasalized according to the rules stated in section 2.2.1.

i) The monophthongs /i, e, o, u/, when followed by /N/, may have nasalized diphthong exponents, as shown below:

/ i / :	[ĩĩ]	/'siN/	['sĩĩɲ]	(yes)
/ e / :	[ẽĩ]	/'seN/	['sẽĩɲ]	(without)

/ o / :	[õɵ̃]	/'soN/	['sõɵ̃ŋ]	(sound)
/ u / :	[ũɵ̃]	/au'guN/	[ɑɵ'gũɵ̃ŋ]	(some)

ii) Preceding / ɲ /, all monophthongs can be realised as phonetic diphthongs. In colloquial speech, the palatal nasal may be elided provided the vowel is nasalized.

Examples:

/'viɲu/	['vĩĩɲɵ],	['vĩĩɵ]	(wine)
/'teɲa/	['tẽĩɲa],	['tẽĩa]	(have)
/'baɲa/	['bɜ̃ĩɲa],	['bɜ̃ĩa]	(fat)
/'soɲu/	['sõĩɲɵ],	['sõĩɵ]	(dream)
/'puɲu/	['pũĩɲɵ],	['pũĩɵ]	(fist)

2.2.3. Diphthongs:

a) Nasalized exponents of the diphthongs in BP are listed and examplified below; in all instances cited in this section, only exponents which are phonetic diphthongs are given. Diphthongs may occur before /N/ or before a nasal phoneme. However, some diphthongs do not occur before /N/ and some diphthongs do not occur before a nasal phoneme. We will list the exponents of the diphthongs according to this type of restriction.

i) Diphthongs which may occur before /N/ :

Diphthongs of the class V_i :

/ ai / :	[ɜ̃ĩ]	/'maiN/	['mɜ̃ĩɲ]	(mother)
/ oi / :	[õĩ]	/'poiN/	['põĩɲ]	(put)
/ ui / :	[ũĩ]	/'muiNtu/	['mũĩtɵ]	(a lot)

Diphthongs of the class V_u :

/ au / :	[ɜ̃ɵ̃]	/'pauN/	['pɜ̃ɵ̃ŋ]	(bread)
:	[ʌ̃ɵ̃]	/'pauN/	['pʌ̃ɵ̃ŋ]	(bread)

Diphthongs of the class $_uV$:

/ ui /	:	[ʊ̃ĩ]	/kuiNkue'nau/	[kʊ̃ĩŋkʊe'nɐʊ]	(quinquennial)
/ ue /	:	[ʊ̃ẽ]	/fre'kueNti/	[fɾe'kʊ̃ẽntɪ]	(frequent)
/ ua /	:	[ʊ̃ɐ̃]	/'kuaNdu/	['kʊ̃ɐ̃ndʊ]	(when)

ii) Diphthongs which may occur before a nasal phoneme: the nasalization is optional.

Diphthongs of the class V_i :

/ ei /	:	[ẽĩ]	/'xeinu/	['xẽĩnʊ]	(kingdom)
/ ai /	:	[ɐ̃ĩ]	/'paina/	['pɐ̃ĩna]	(cotton)
/ oi /	:	[õĩ]	/'boina/	['bõĩna]	(beret)
/ ui /	:	[ũĩ]	/axui'nax/	[axũĩ'naɾ̥]	(to ruin)

Diphthongs of the class V_u :

/ iu /	:	[ĩʊ̃]	/'fiumi/	['fĩʊ̃mɪ]	(film)
/ ɛu /	:	[ɛ̃ʊ̃]	/'sɛuma/	['sɛ̃ʊ̃ma]	(a name)
/ au /	:	[ɐ̃ʊ̃]	/'kauma/	['kɐ̃ʊ̃ma]	(calm)
/ ou /	:	[õʊ̃]	/'oumu/	['õʊ̃mʊ]	(elm)
/ uu /	:	[ũʊ̃]	/kuumina'sauN/	[kũʊ̃mina'sɐ̃ʊ̃]	(culmination)

No diphthong of the class $_uV$ occurs before a nasal phoneme within words.

b) The diphthongs of the class V_i when followed by /N/ may be realised either by a diphthong or by a monophthong, as shown by the examples below:

/ ai /	:	[ɐ̃ĩ]	/'maiN/	['mɐ̃ĩ^{ɲ}]	(mother)
	:	[ɐ̃]	/'maiN/	['mɐ̃^{ɲ}]	(mother)
/ oi /	:	[õĩ]	/'poiN/	['põĩ^{ɲ}]	(put)
	:	[õ]	/'poiN/	['põ^{ɲ}]	(put)
/ ui /	:	[ũĩ]	/'muiNtu/	['mũĩ^{ɲ}tʊ]	(a lot)
	:	[ũ]	/'muiNtu/	['mũ^{ɲ}tʊ]	(a lot)

c) The diphthong /ue/ , when followed by /N/, may be realised by a diphthong or by a triphthong, as shown below:

Examples:

/ ue /	:	[ɷ̃ẽ]	/fre'kueNti/	[fɾe'kɷ̃ẽntι]	(frequent)
	:	[ɷ̃ẽĩ]	/fre'kueNti/	[fɾe'kɷ̃ẽĩntι]	(frequent)

2.2.4. Triphthongs:

a) No triphthong occurs preceding a nasal phoneme within words. There are only two types of diphthongs which occur before /N/: /uau/ and /uoi/. They are always stressed and preceded by a velar stop. They represent the singular and the plural forms of some words, and therefore, they occur only in wordfinal position. Their phonetic realisations are given below:

/ uau /	:	[ɷ̃ɜ̃ɷ̃]	/sa'guauN/	[sa'gɷ̃ɜ̃ɷ̃]	(lobby)
	:	[ɷ̃ʌ̃ɷ̃]	/sa'guauN/	[sa'gɷ̃ʌ̃ɷ̃]	(lobby)
/ uoi /	:	[ɷ̃õĩ]	/sa'guoiNs/	[sa'gɷ̃õĩs]	(lobbies)

b) The triphthong /uoi/ may be realised by a triphthong or by a nasalized diphthong, as shown below:

/ uoi /	:	[ɷ̃õĩ]	/sa'guoiNs/	[sa'gɷ̃õĩs]	(lobbies)
	:	[ɷ̃õ]	/sa'guoiNs/	[sa'gɷ̃õɲs]	(lobbies)

2.2.5. Partial Nasalization of Diphthongs and Triphthongs:

All the diphthongs of the class $_{u}V$ and all the triphthongs, when followed by /N/, may have their phonetic exponents fully nasalized or partially nasalized. In the latter case, the diphthong or triphthong will have an oral beginning, but a nasalized ending, as shown by the following examples:

/'kuaNdu/	['kɷ̃ɜ̃ndɷ],	['kɷɜ̃ndɷ]	(when)
/fre'kueNti/	[fɾe'kɷ̃ẽntι],	[fɾe'kɷẽntι]	(frequent)
/sa'guauN/	[sa'gɷ̃ɜ̃ɷ̃],	[sa'gɷɜ̃ɷ̃]	(lobby)

/sa'guoiNs/ [sa'gʊ̃õɩ̃s] , [sa'goõɩ̃s] (lobbies)

2.2.6. Summary:

In this chapter on vowel nasality, we have seen a complex relationship between phoneme and (nasalized) phonetic exponent in which

i) monophthong vowel phonemes may be realised as phonetic monophthongs and diphthongs;

ii) diphthong vowel phonemes may be realised as phonetic diphthongs and monophthongs and triphthongs;

iii) triphthong vowel phonemes may be realised as phonetic triphthongs and diphthongs.

It is, therefore, useful, to conclude this section by listing (nasalized) phonetic monophthongs, diphthongs and triphthongs, and the phonemes from which they are derived.

a) Phonetic monophthongs and the phonemes from which they are derived (see sections 2.2.2. (a-c), and 2.2.3. (b)).

[ĩ]	:	/ i /	/'siN/	['sĩɲ]	(yes)
[ɩ̃]	:	/ i /	/iNsta'lax/	[ɩ̃sta'lar̥]	(to install)
	:	/ e /	/eNse'ada/	[ɩ̃sɩ'ada]	(cove)
[ẽ]	:	/ e /	/'seN/	['sẽɲ]	(without)
[ɛ̃]	:	/ ɛ /	/'trɛmi/	['trɛ̃mɩ]	(he trembles)
[ɜ̃]	:	/ a /	/'saN/	['sɜ̃ŋ]	(healty)
	:	/ ai /	/'maiN/	['mɜ̃ɲ]	(mother)
[ɔ̃]	:	/ ɔ /	/'ɔme^{N} /	['ɔ̃mẽɲ]	(man)
[õ]	:	/ o /	/'soN/	['sõŋ]	(sound)
	:	/ oi /	/'poiN/	['põɲ]	(put)
[ʊ̃]	:	/ o /	/koN'prida/	[kʊ̃m'prida]	(long)
	:	/ u /	/kuN'prida/	[kʊ̃m'prida]	(accomplished)

[ũ]	:	/ u /	/'xuN/	['xũŋ]	(rum)
	:	/ ui /	/'muiNtu/	['mũɲto]	(a lot)

b) Phonetic diphthongs and the phonemes from which they are derived (see sections 2.2.2. (e), 2.2.3. and 2.2.3. (c)).

[ĩɩ̃]	:	/ i /	/'siN/	['sĩɩ̃ɲ]	(yes)
[ẽɩ̃]	:	/ e /	/'seN/	['sẽɩ̃ ɲ]	(without)
[ɜ̃ɩ̃]	:	/ ai /	/'maiN/	['mɜ̃ɩ̃ɲ]	(mother)
	:	/ a /	/'baɲa/	['bɜ̃ɩ̃ɲa]	(fat)
[õɩ̃]	:	/ oi /	/'poiN/	['põɩ̃ɲ]	(put)
	:	/ o /	/'soɲu /	['sõɩ̃ɲo]	(dream)
[ũɩ̃]	:	/ ui /	/'muiNtu/	['mũɩ̃ɲto]	(a lot)
	:	/ u /	/'puɲu /	['pũɩ̃ɲo]	(fist)
[ĩʊ̃]	:	/ iu /	/'fiumi/	['fĩʊ̃mɩ]	(film)
[ẽʊ̃]	:	/ eu /	/xeuma'tismu/	[xẽʊ̃ma'tizmo]	(rheumatism)
[ɛ̃ʊ̃]	:	/ ɛu /	/'sɛuma /	['sɛ̃ʊ̃ma]	(a name)
[ɑ̃ʊ̃]	:	/ au /	/'kauma/	['kɑ̃ʊ̃ma]	(calm)
[ɜ̃ʊ̃]	:	/ au /	/'pauN/	['pɜ̃ʊ̃]	(bread)
[ʌ̃ʊ̃]	:	/ au /	/'pauN/	['pʌ̃ʊ̃]	(bread)
[õʊ̃]	:	/ ou /	/'oumu/	['õʊ̃mo]	(elm)
	:	/ o /	/'soN/	['sõʊ̃]	(sound)
[ũʊ̃]	:	/ uu /	/kuumina'sauN/	[kũʊ̃mina'sɜ̃ʊ̃]	(culmination)
	:	/ u /	/au'guN/	[ɑo'gũʊ̃]	(some)
[ʊ̃ĩ]	:	/ ui /	/kuiNkue'nau/	[kʊ̃ĩŋkoe'nɑo]	(quinquennial)
[ʊ̃ẽ]	:	/ ue /	/fre'kueNti/	[fɾe'kʊ̃ẽntɩ]	(frequent)
[ʊ̃õ]	:	/uoi/	/sa'guoiNs/	[sa'gʊ̃õɲ s]	(lobbies)
[ʊ̃ɜ̃]	:	/ ua /	/'kuaNdu/	['kʊ̃ɜ̃ndo]	(when)

c) Phonetic triphthongs and the phonemes from which they are derived (see sections 2.2.3. (c), and 2.2.4. (b)).

[ɔ̃ẽĩ]	:	/ue/	/fre'kueNti/	[fre'kɔ̃ẽĩntɩ]	(frequent)
[ɔ̃õĩ]	:	/uoi/	/sa'guoiNs/	[sa'gɔ̃õĩs]	(lobbies)
[ɔ̃ɜ̃ɔ̃]	:	/uau/	/sa'guauN/	[sa'gɔ̃ɜ̃ɔ̃]	(lobbies)
[ɔ̃ʌ̃ɔ̃]	:	/uau/	/sa'guauN/	[sa'gɔ̃ɜ̃ɔ̃]	(lobby)

2.3. Consonantal Nasality

Exponents of the nasals have already been considered earlier (Part I, Chapter 1, Section 1.9.5. and Chapter 2, Section 2.2.2., e (ii)). In the present section, only the consonantal exponents of /N/ will be considered.

2.3.1. Consonantal Exponents of /N/ :

Phonetic exponents of /N/ have already been given earlier (see Chapter 1, Section 1.3.). Some problems related to the occurrence of the exponents of /N/ in certain contexts are discussed below.

a) In wordfinal position:

In the present analysis, the syllable in wordfinal position may have a nasalized diphthong optionally followed by a nasal, or may have an optionally nasalized monophthong or an oral diphthong followed by a nasal phonetically. The occurrence of nasalized monophthongs with no accompanying nasal is restricted to [ɜ̃], an exponent of /a/. In the literature, however, it has been suggested that [ĩ, ẽ, õ, ũ] could also occur in wordfinal position without any accompanying nasal (Hall 1943: 2-3; Wise 1957; Head 1964: 189). I have investigated the pronunciation of speakers of different dialects of Brazil, Portugal and Moçambique, and I have not come across this phenomenon in any of my informants.

Rousselot reports that the nasal which may occur following a nasalized diphthong in wordfinal position, is a velar nasal. Using kymography and palatography, he investigated the words mão (hand), melões (melons), mãe (mother), põe (put), pães (bread) and cães (dogs). He says:

> "In all these words, the two vowels of the diphthong are nasalized and followed by a nasal consonantal element, in which the airstream goes out only from the nose... It is easy to determine the nasal consonant that follows the diphthong using a false palate. It is a velar n" (Rousselot 1924: 557 - the translation is mine; see Appendix 1 (b)).

The phonetic nature of the palatal and velar nasals as exponents of /N/ in wordfinal position before pause, needs to be considered now. Postvocalically, the palatal and the velar nasals have a place of articulation which is slightly retracted palatal and velar (see Fig. 1 , palatograms: 5, 7, 11 and 12). They are unreleased nasals in the sense that towards the end of their articulation, when there is still an articulatory closure in the mouth, the vocal cords stop vibrating and airflow pressure decreases rapidly behind the oral blockage, so that when the closure is removed, no sound is produced. At that point, there is usually a well increased level of nasal airflow. When these nasals occur as unreleased nasals at the end of words, principally before pause, they have an auditory effect similar to a hum without noticeable differentiation between them in terms of place of articulation. Head (1964: 189) observes that these nasals in wordfinal position are sometimes 'suppressed', present 'low audibility' or are 'not articulated with complete closure of the oral passage'.

In Fig. 1 , palatogram (1) shows a pronunciation of the word vem (come) with [ẽ] and no accompanying nasal (artificial pronunciation) to be compared with the usual pronunciations

Fig. 1 Palatograms of Brazilian Portuguese words to show how the process of nasalization interacts with articulatory processes.

Palatograms:

1 - 3 - 5 Three variant forms of the pronunciation of the word <u>vem</u>: ['vẽ], ['vẽĩ] and ['vẽɲ].

4 - 6 Two variant forms of the pronunciation of the word <u>mãe</u>: ['mɜ̃ĩ] and ['mɜ̃ĩɲ].

11 - 12 Two variant forms of the pronunciation of the word <u>finca</u> : with a homorganic velar nasal:['fĩŋka] , and with a palatal nasal: [fĩɲka] between the nasalized close front vowel and the velar stop.

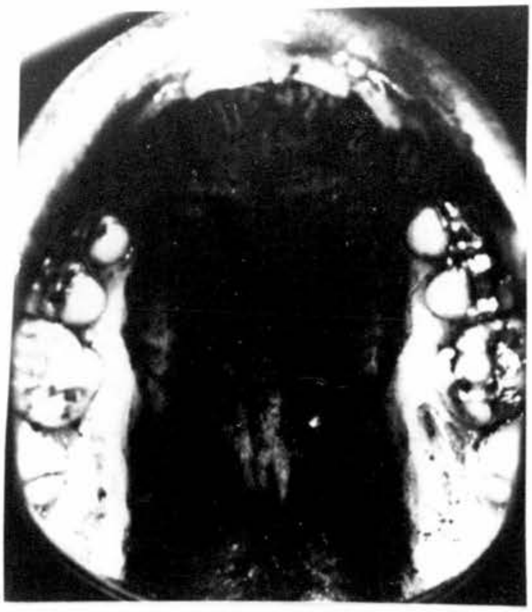
8 - 10 Two verbal forms of <u>fingir</u> : '<u>finge</u>': [fĩʒɩ] and '<u>finja</u>'['fĩɲʒa], with the occurrence of a nasal between the nasalized vowel and the fricative, and without the nasal.

2 - 8 Non-occurrence of nasal between a nasalized vowel and a fricative in the words <u>mancha</u> ['mɜ̃ʃa] and <u>finge</u> ['fĩʒɩ].

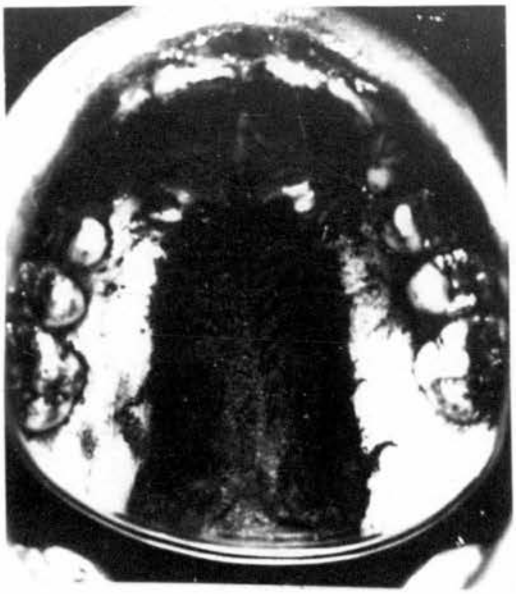
7 - 9 Occurrence of unreleased nasals in wordfinal position, in the case of <u>vão</u>['vɜ̃õŋ] and <u>vim</u> ['vĩɲ].

10 - 12 Illustration of the occurrence of a nasal between a nasalized vowel and a consonant conditioned by the preceding vowel.

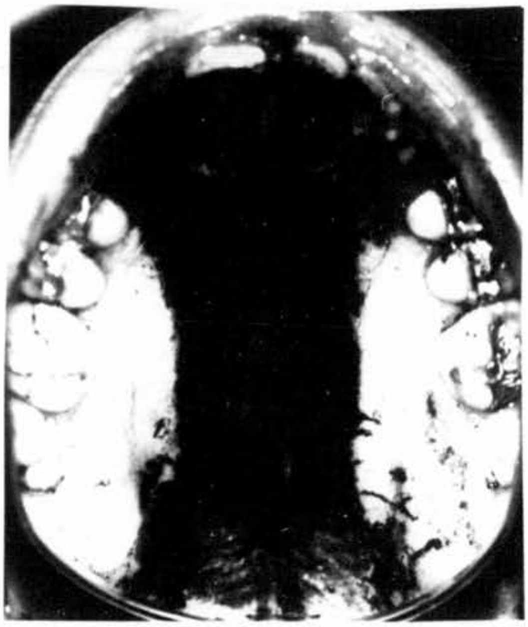
11 Illustration of the occurrence of a (homorganic) nasal between a nasalized vowel and a stop, conditioned by the following consonant.



1. <u>vem</u> [vẽ]



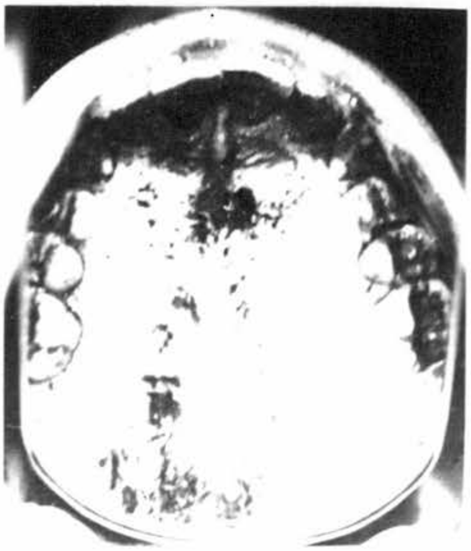
2. <u>mancha</u> [mɜ̃ʃa]



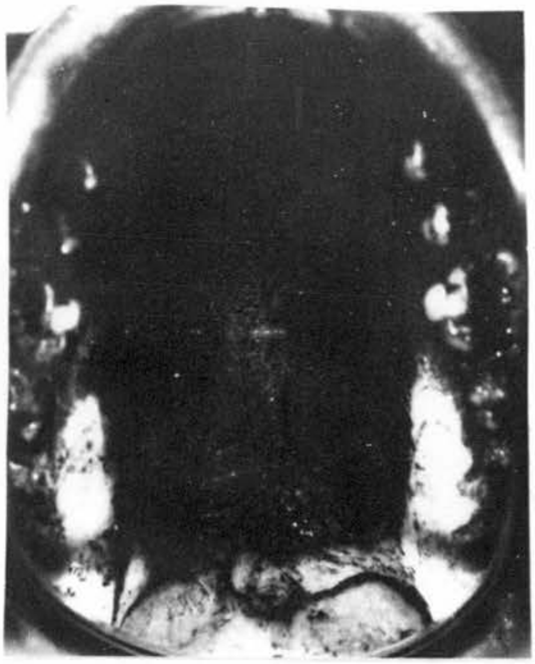
3. <u>vem</u> [vẽĩ]

4. <u>mãe</u> [mɜ̃ĩ]

5. <u>vem</u> [vẽɲ]

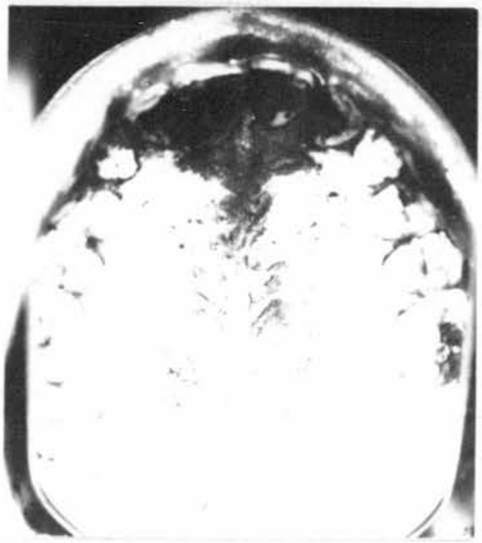


6. <u>mãe</u> [mɜ̃ĩɲ]



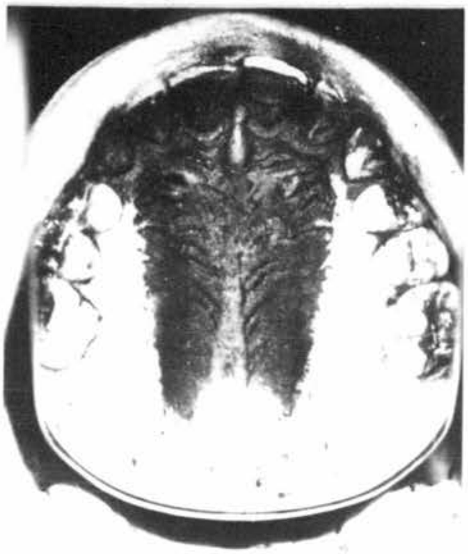
7. <u>vão</u> [vɜ̃ɶ̃ŋ]

8. <u>finge</u> [fĩʒɩ]



9. <u>vim</u> [vĩɲ]

10. <u>finja</u> [fĩɲʒa]



11. <u>finca</u> [fĩŋka]

12. <u>finca</u> [fĩɲka]

illustrated on palatograms (3) and (5). Palatograms (4) and (6) show two different pronunciations of the word mãe (mother), one without a final nasal and the other with a final nasal. Palatogram (7) shows the occurrence of a nasal at the end of the word vão (they go). Palatogram (9) shows an unreleased palatal nasal in the word vim (I came).

b) Exponents of /N/ when postvocalic and followed by a consonant within words:

According to the rules presented earlier (Part I, Chapter 1, Section 1.3.), in the context between a vowel and a consonant within words, /N/ may or may not have a consonantal exponent. When it has a consonantal exponent, the exponent will be a nasal whose place of articulation is conditioned either by the preceding vowel or by the following stop. If a nasal occurs before a continuant consonant, the place of articulation of the nasal is always conditioned by the preceding vowel.

Examples:

/'kaNta/	['kɜ̃ta],	['kɜ̃ŋta],	['kɜ̃nta]	(sing)
/'peNti/	['pẽtɩ],	['pẽɲti],	['pẽntɩ]	(comb)
/'eNʃi/	['ẽʃɩ],	['ẽɲʃɩ]		(fill)
/'oNsa/	['õsa],	['õŋsa]		(lynx)

The exponents of /N/ in the context between a vowel and a consonant within words, have been interpreted differently by some writers. A brief review of the literature will be considered now.

The large majority of writers on Portuguese accept the occurrence of a homorganic nasal between a nasalized vowel and a stop medially (G. Viana 1892: 52-53; Nobiling 1903: 136-137; Reed and Leite 1947: 196; Lacerda and Hammarstrøm 1952; Wise 1957;

M. Câmara 1971: 30; Pontes 1972: 22; Lipski 1975: 68). Some authors interpret the occurrence of a nasal as prenasalization of the stop (Hall 1943; Feldman 1967; Mioni 1973: 297-298). Lipski (1975: 65, 68-69) suggests that any kind of consonant can be prenasalized when preceded by a nasalized vowel medially, and Head (1964: 187-189) states that any kind of consonant may have a homorganic nasal preceding it when the nasal occurs following a nasalized vowel. Many writers have pointed out that no nasal occurs between a nasalized vowel and a continuant consonant (G. Viana 1892: 52-53; Nobiling 1903: 136-137; Lacerda and Hammarstrøm 1952; M. Câmara 1971: 30; Pontes 1972: 22). Wise (1957) says that a homorganic labiodental nasal may also occur in BP, preceding a labiodental fricative. Dahl's (1964: 315) interpretation coincides largely with the interpretation of the present dissertation.

The occurrence of homorganic nasals before stops is not an obligatory rule, but a possibility that occurs occasionally. Experimental studies (see Part VI, Chapter 4) have shown that postvocalic nasals vary in duration in BP. Homorganic nasals are quite often very short in duration (approximately 20 - 50 msec). With such a short duration, the homorganic nasal is barely audible, even when the word is said in isolation. Some short homorganic nasals originate from nasalization over the initial part of stops (their closure phase) when preceded by nasalized vowels.

Kymographic and pneumotachographic traces also indicate that velic delay can also occur carrying the nasal airflow over the beginning of fricatives and laterals, preceded by nasalized vowels in BP (see Part VI, Chapter 1 and 4). But, it has been observed too, that the ear does not perceive any kind of 'fricative' or 'lateral' nasal between the nasalized vowel and the fricative or lateral, even when the nasal airflow is still present for a resonable duration over the fricative or lateral. This is due, probably, to the fact that the nasal airflow pressure under these circumstances, is of very low level, and the oral airflow pressure is considerably higher in comparison with the pressure of the nasal airflow (see Part VI, Chapter 3). Because the occurrence of short homorganic nasals revealed in experiments are practically undetectable by ear, it is unnecessary and perhaps not convenient to transcribe them in normal phonetic transcriptions of BP.

In Fig. 1 , palatogram (2) and (8) illustrate /N/ between a nasalized vowel and a fricative without any nasal exponent. Palatograms (10) and (12) shows the occurrence of a palatal nasal conditioned by the preceding vowel, and palatogram (11) illustrates the occurrence of a velar nasal homorganic to the following velar stop. Palatograms (11) and (12) shows two variant pronunciations of the word finca (drive in). The author was the subject for all palatograms in Fig. 1.

Finally, we must say that although all the phonetic variants indicated here for the context under discussion, represent possibilities of occurrence, some variants are more frequently found than others in specific cases. For example, there is usually no nasal between a nasalized vowel and a fricative; it is quite common to have a short homorganic nasal to a following stop; it is more frequent to have a nasal conditioned by a front vowel than by a vowel that is not a front one in the same type of context.

2.4. Nasality and Liaison

In the structure of words in Portuguese, there is the following restriction: when two syllables are put together, the second syllable will never start with a vowel, when the first syllable ends with a consonant. The same constraint exists in connected speech involving the last syllable of one word and the first syllable of the next word, when there is no pause between them.

According to the syllable patterns of the language, however, a word may end with /s, x, N/; and the next word may start with any vowel phoneme. When these two words occur in connected speech without an intervening pause, there is a re-arrangement in the distribution of the segments of the adjacent syllables, so avoiding the production of a structure which is not allowed in the language. This re-arrangement is known in the literature as 'liaison'. Liaison is governed by the following rule: when /s, x, N/ occur as the last segment in an isolated word, and this word is followed by another word, whose first segment is a vowel phoneme, the exponents of the phonemes /s, x, N/ leave the final position in the first word and become word initial in the second word. Thus, the syllable boundary at the junction of the two words shifts one segment to the left.

The phonemes /s, x/ conditioned by the fact that they are involved in the 'liaison', have the exponents [z, ɾ]. /N/ is represented by [ɲ] or [ŋ] depending on the preceding vowel, in the same way they may occur when the word is in isolation (see Part I, Chapter 1, Section 1.3.).

Some people like M. Câmara (1970, 1971) have treated the /s/ and /x/ as archiphonemes in wordfinal position. However, there is no need for that, since the phonemes /x, s/ have different variants conditioned by different environments. In fact, even when liaison occurs, there is no opposition between /x/ and /r/ or between /s/ and /z/ as suggested by many people, but complementary distribution.

Examples:

Words in isolation:

/a ka 'bax/	[a ka 'bar̥]	(to finish)
/a 'ʃaN du/	[a 'ʃɜ̃n dʊ]	(finding)
/xa 'ʃaN du/	[xa 'ʃɜ̃n dʊ]	(cracking)

In connected speech:

/a ka 'bax a 'ʃaN du/	[a ka 'ba ɾa 'ʃɜ̃n dʊ]	(to finish finding)
/a ka 'bax xa 'ʃaN du/	[a ka 'bar̥ xa 'ʃɜ̃n dʊ]	(to finish cracking)

Words in isolation:

/'ɛs/	['ɛs]	(you are)
/'a biu/	['a biʊ]	(handy)
/'sa biu/	['sa biʊ]	(wise)

In connected speech:

/'ɛs 'a biu/	['ɛ 'za biʊ]	(you are handy)
/'ɛs 'sa biu/	['ɛ 'sa biʊ]	(you are wise)

Words in isolation:

/'veN/	['vẽɲ]	(come)
/a 'ki/	[a 'ki]	(here)

In connected speech:

/'veN a 'ki/	['vẽ ɲa 'ki]	(come here)

Words in isolation:

/'laN/	['lɜ̃ŋ]	(wool)
/a 'zuu/	[a 'zuʊ]	(blue)

In connected speech:

/'laN a 'zuu/	['lɜ̃ ŋa 'zuʊ]	(blue wool)

In the case of /N/, the phenomenon of liaison takes place only when the /N/ is realized phonetically by a nasal. When the /N/ is not realized phonetically by a nasal, there is no liaison, and this happens more frequently when the first word ends with one of the two nasalized diphthongs: [ʌ̃ɔ̃] as the exponent of /au/ and [õɔ̃] as the exponent of /o/.

Examples:

Words in isolation:

/'mauN/	['mʌ̃ɔ̃]	(hand)
/a 'bɛ x ta/	[a 'bɛr̥ ta]	(open)

In connected speech:

/'mauN a 'bɛx ta/	['mʌ̃ɔ̃ a 'bɛr̥ ta]	(open hand)

Words in isolation:

/'boN/	['bõɔ̃]	(good)
/'ɔ meN/	['ɔ mẽɲ]	(man)

In connected speech:

/'boN 'ɔ meN/	['bõɔ̃ 'ɔ mẽɲ]	(good man)

The phenomenon of liaison in Portuguese has been reported in phonetic works since the late 19th century (G. Viana 1892; Dahl 1964: 314; Head 1964: 157; M. Câmara 1970: 50-51; Mioni 1973: 304-305; Lipski 1975: 66). However, the phonetic specification of the phenomenon of liaison has been the object of some controversy, mainly when the first word ends in /N/. Certain writers do not accept the presence of nasals in wordfinal position following a nasalized vowel, and therefore, this word cannot be involved in cases of liaison when in connected speech (see G. Viana 1892, and Hall's comments in Reed and Leite 1947: 197).

PART II : ANATOMY AND PHYSIOLOGY OF THE VELOPHARYNGEAL MECHANISM

Chapter 1 : The Anatomy of Some Structures Involved in the Production of Nasality

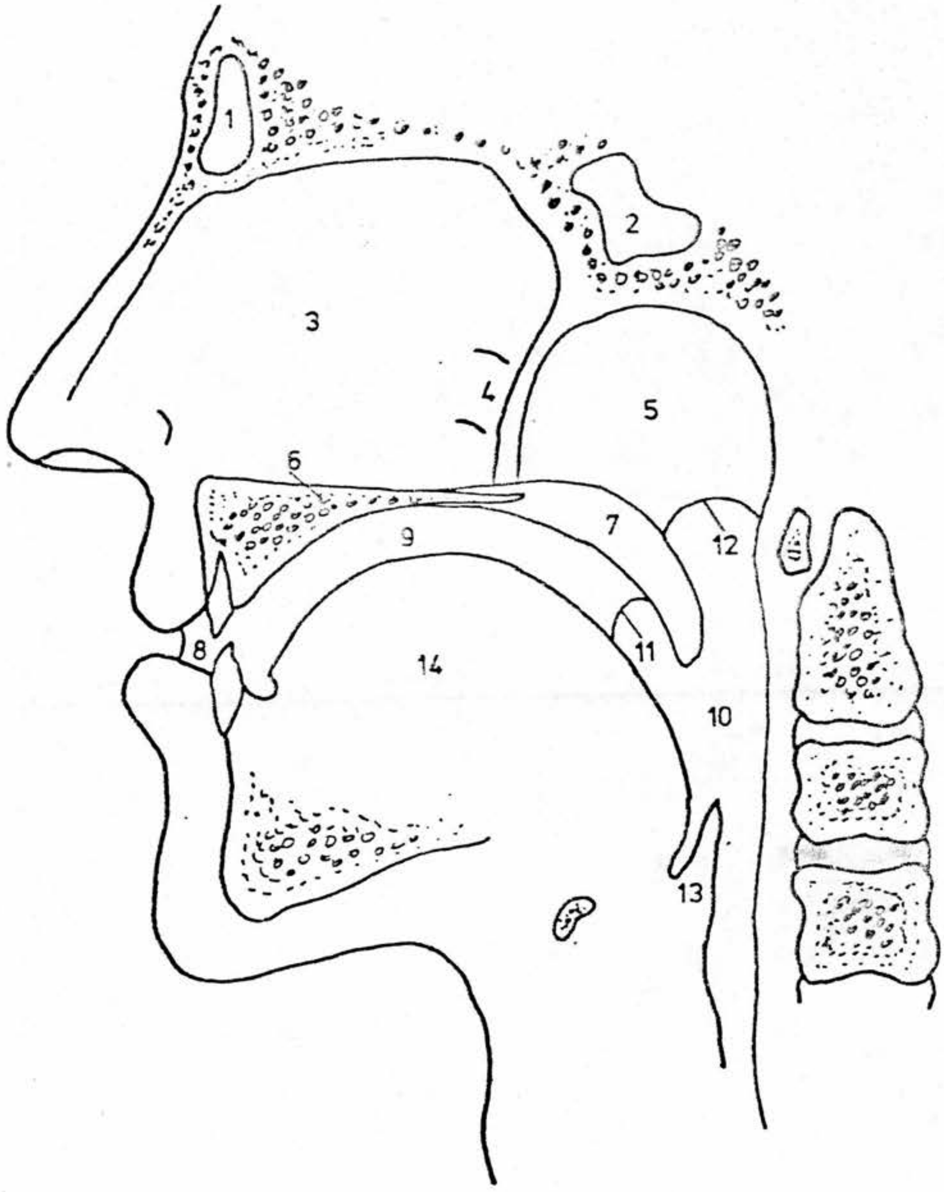
1.1. The Cavities of the Vocal Tract

We will proceed with the study of the anatomy and physiology of the velopharyngeal mechanism by making some general comments about the cavities of the vocal tract firstly. Then, the most important structures involved in the production of nasality will be discussed separately. Finally, a description of the mechanical movements of the soft palate will be given.

The vocal tract can be seen as a non-uniform tube from the glottis to the lip opening (see Fig. 2). In speech, the configuration of the tube varies constantly in making the necessary adjustments of the movable parts required to produce the correct sound. The non-uniformity of the tube is not only due to its movable parts, but also to the specific anatomic configuration of the supraglottal cavities.

The vocal tract is a set of different and interconnected cavities. It is a simplistic view of the vocal tract to think of the supraglottal cavities as being made up of only the pharynx, the mouth and the nose cavity. To understand the acoustic characteristics of real speech, a much more complex model of the vocal tract will be necessary.

It is common practice in phonetics teaching and publications to show the vocal tract as a two-dimensional structure. See, for example, this suggestion in Fig. 2 . This is very convenient as a didactical procedure. But the illustration of different articulations shown in two-dimensional diagrams gives us only a gross approximation of what actually happens in the vocal tract during a frozen point in time.



1. Frontal sinus
2. Sphenoid sinus
3. Nasal cavity
4. Nares
5. Nasopharynx
6. Hard palate
7. Soft palate
8. Labial cavity
9. Mouth cavity
10. Oropharynx
11. Oral port
12. Nasal port
13. Epiglottis
14. Tongue

Fig. 2 Schematic diagram showing the major supraglottal cavities and some structures of the vocal tract.

Certainly, a more sophisticated investigation of the articulatory gestures should incorporate a better description of the highly complex configurations formed inside the vocal tract during speech. A better description of the vocal tract is very important in the study of speech sounds in general, and indispensable in the study of different voice qualities, as for example, of nasality.

We are accustomed to attribute the responsibility for the production of speech sounds to the configurations of the vocal tract cavities. The acoustic role played by the major cavities in the production of speech is quite well understood, but we know very little about how the minor cavities of the vocal tract influence the spectrum of the sounds.

Early experiments with synthetic speech contributed useful results, helping to explain the principal features of speech with very simplified models of the vocal tract (Chiba and Kajiyama 1958; Stevens et al. 1953). Very few researches into the function of the minor cavities have been caried out (Fant 1960; Lindqvist and Sundberg 1976). In fact, we must say that synthetic speech provided us with a good insight into the relationship between acoustics and perception, but very little information about the relationship between the acoustics and physiology of speech (Stevens et al. 1953).

The production of nasality is a very complex problem and related in particular to the formation of resonator side chambers in the vocal tract. So, any attempt to shed light on the subject of nasality, will be involved in one way or another with the discussion of the role played by small cavities of the vocal tract in the production of speech.

In the present work, a special emphasis is given to the anatomy and physiology of structures which are directly or indirectly related to the production of nasality. This will lead us to work with a more complex model of integrated cavities in the vocal tract than the exclusive use of the pharyngeal, the oral and the nasal cavities. For example, the movements of the epiglottis can change the configuration of the vocal tract in such a way that a side chamber is formed between the tongue and the epiglottis in the lower pharynx, with the consequent introduction of a special voice quality to speech. Russell (1931: 42) and West et al. (1937: 79) have specifically suggested, for example, that nasality can be produced by this special positioning of the epiglottis, especially the nasality that characterizes the so-called nasal twangs.

There is a lot of evidence from the literature showing that the volume of the nasopharynx can be modified not only by velic movements, but also by compression of the lateral walls of that cavity (Harrington 1944; Zwitman et al. 1974; Zagzebski 1975). This change in volume must have important acoustic consequences in the production of speech when the nasopharynx is coupled into the rest of the vocal tract (Delattre 1969a and 1969b). Yet, although we can infer acoustical consequences theoretically from the modifications of the nasopharynx volume, we do not have enough data from experiments to describe exactly how the nasopharynx influences the final output of speech.

The connection of the nasopharynx to the inner ear via the eustachian tube, whose opening is located high in the lateral walls of the nasopharynx, may have some relevance ~~on~~ to how a person learns to recognize speech sounds. Looking at the vocal tract as a set of integrated cavities, each of them contributing to the final output, it is surprising to find that the internal connection to the inner ear ends in the nasopharynx, rather than in a place where speech is found in a more advanced stage of production in relation to the final output. This is more striking when we take into account the fact that the nasopharynx is cut off from the active part of the vocal tract during the production of oral sounds. It seems very unlikely that this connection with the inner ear has no relevance at all in the speech process. Furthermore, althought a cavity like the nasopharynx seems so important in the mechanism of speech, in fact, we do not know very much about its role in the speech process.

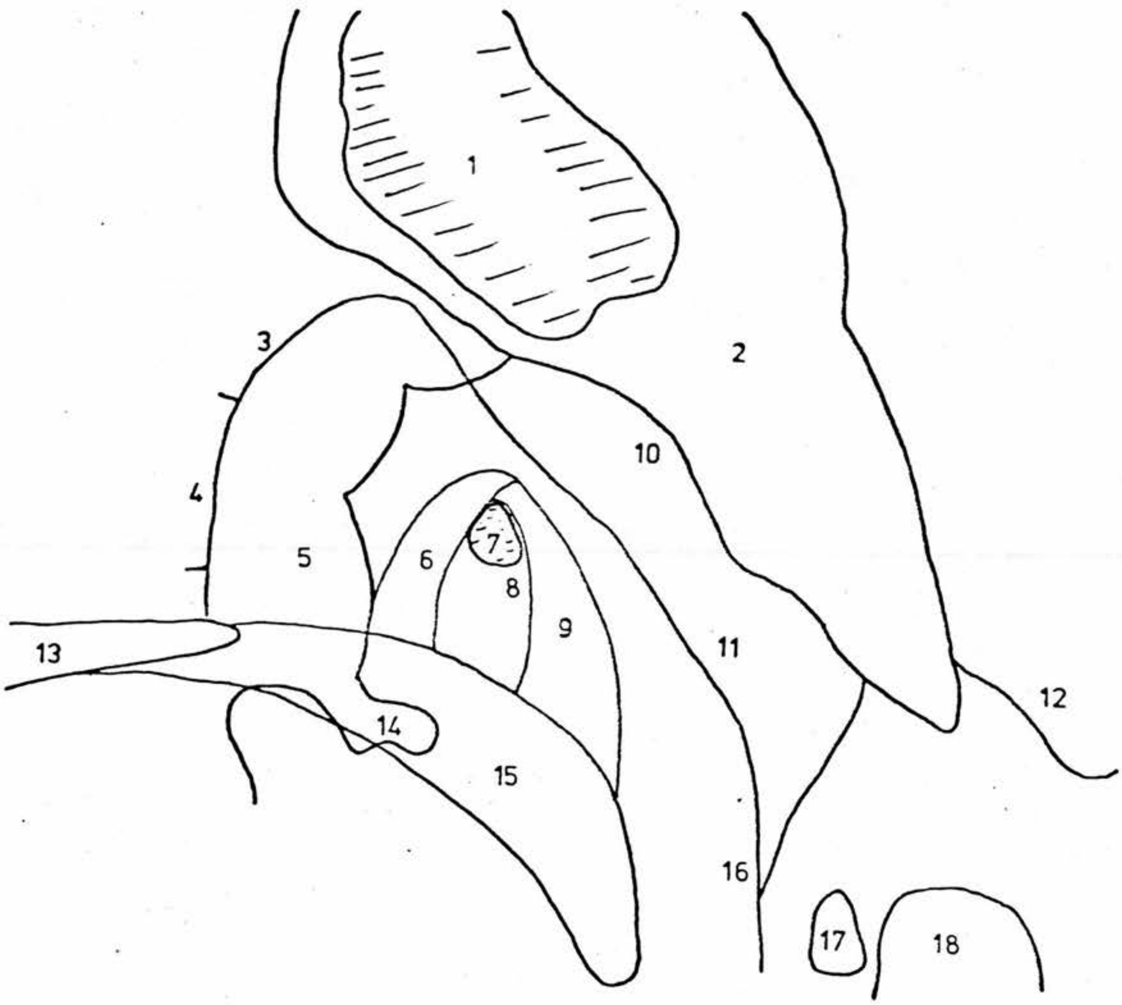
Finally, we have mentioned some problems related to the function of the supraglottal cavities, but many researchers have pointed out that the infraglottal cavities, such as the trachea, the lungs and the oesophagus may play a part in the production of the quality of the sounds in speech (Pike 1943: 85-87; van den Berg 1962).

More information about the configuration of the vocal tract in the production of speech will be given in the next sections, where a more detailed discussion of the anatomy and physiology of speech production is presented. It is also interesting to see Part III, chapter 2, and Part V of the present work.

1.2. The Anatomy of the Nasopharynx

The nasopharynx has also been referred to as the epipharynx, the upper pharynx and the rhinopharyngeal cavity. It is located at the top of the pharynx and separated from it by the soft palate. It starts a little above the level of the Atlas vertebra, where the velum is in contact with the posterior pharyngeal wall. Then it continues upwards and frontwards following the pharyngeal protuberance of the occipital bone (see Fig. 3). It reaches its upper limit at the rostrum of the sphenoid bone.

The roof of the nasopharynx is shaped by the sphenoid bone, which slopes downwards, until it reaches the septum bone and the posterior choanae of the nasal cavities, where the two posterior nares



1. Sphenoid sinus
2. Sphenoid bone
3. Septum bone
4. Posterior choanae of the nasal cavity
5. Medial pterygoid plate
6. Salpingopalatine fold
7. Pharyngeal ostium of eustachian tube
8. Torus tubarius
9. Salpingopharyngeal fold
10. Fossa of Rosemüller
11. Pharyngeal tonsil
12. Occipital bone
13. Hard palate (aponeurosis)
14. Hamulus
15. Soft palate
16. Passavant's cushion
17. Atlas vertebra
18. Cervical vertebra

Fig. 3 Sagittal section through the nasopharynx to show the anatomy of the area.

are located. Thus the nasopharynx is interconnected with the nasal passages. Figure 3 shows the location of all these parts schematically.

The floor of the nasopharynx is formed by the soft palate, and is, therefore, variable according to the position of the velum. When the velum is raised, the floor is horizontal, following the floor surface of the inferior turbinate of the nasal cavity.

Laterally, the nasopharynx is made up of a complex system of muscles and other tissues (Zemlin 1968: 304). The muscles of the lateral walls are: levator palatini, tensor palatini, salpingopalatini, salpingopharyngeus and superior constrictor (see Part II, Chapter 2, section 2.1.). The salpingopalatini and salpingopharyngeus make up the salpingopalatine and salpingopharyngeal folds. These two folds join together in the upper part of the lateral walls, where there is a protuberance called the torus tubarius (see illustrations on Fig. 3). Inside the junction of the folds and surrounded by the torus tubarius, there is the pharyngeal ostium of the eustachian tube, i.e., the opening of the auditory tube connecting the nasopharynx to the inner ear.

The posterior wall and the roof of the nasopharynx usually have a concave configuration, the deepest part of which is called the fossa of Rosemüller. The fossa is covered by the pharyngeal tonsil or adenoids (see Part II, Chapter 1, section 1.6.). In some individuals, this tissue grows to such an extent that the fossa is completely filled and the typical configuration of the area assumes a convex shape (Zemlin 1968: 301). In pathological cases, the adenoids interfere severely with the velopharyngeal mechanism. At the point where the velum touches the posterior pharyngeal wall, or slightly below this point, there is sometimes a muscular bulge, called

Passavant's cushion (see Part II, Chapter 2, section 2.3.).

In the examination of the size of the nasopharynx in a subject with a facial defect, Calnan estimated that

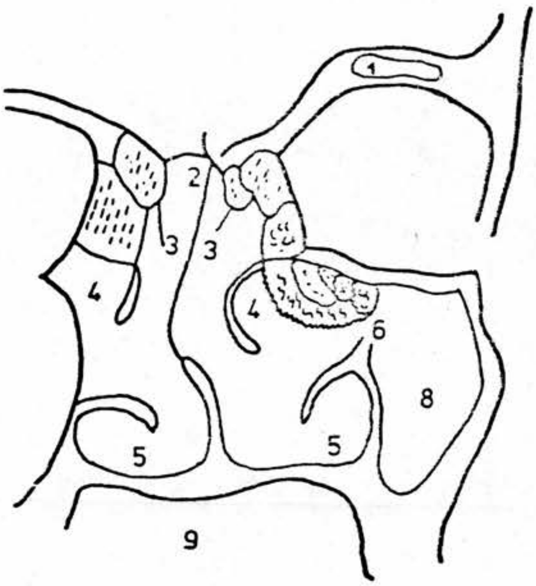
> "The transverse diameter of the nasopharynx was about 3 cm, but the anteroposterior measurement was 1 cm or less... and only the anterior one-third of the velum could be seen from above" (Calnan 1955: 15).

Data from other investigations showed different sizes (Björk 1961; Bjuggren and Fant 1964). Bjuggren and Fant (1964: 6) observed that the size of the nasopharynx may vary considerably among individuals.

In the phonetic literature, the nasopharynx has been classified as part of what is usually said to be the 'nasal cavity' or part of the pharynx (the epipharynx), or as a separate cavity with its own resonating characteristics.

The nasopharynx constitute a separate resonator when the velum is in a relatively high position (Bjuggren and Fant 1964: 6). The nasopharynx and the oropharynx can be regarded as a single resonator cavity when the velum is almost perpendicularly lowered. On the other hand, the outlet of the nasopharynx leading into the nasal cavities has a relatively small size and it does not, therefore, prevent the nasopharynx of having its own resonant characteristics, independently from the acoustic characteristics of the nasal chambers. In the present work, a distinction between nasal cavity (or cavities), meaning the nasal chambers, and the nasopharynx is used for different acoustical implications (see Part V).

According to Delattre (1969a and 1969b), the volume of the nasopharynx can be balanced by equal volume in the pharynx, caused by the lowering of the velum and by a special positioning of the back of the tongue. He says that this balance is responsible for the



1. Frontal sinus
2. Perpendicular plate
3. Superior concha (S. turbinate)
4. Middle concha (M. turbinate)
5. Inferior concha (I. turbinate)
6. Opening of maxillar sinus
7. Vomer bone
8. Maxillar sinus
9. Mouth cavity

3, 4, 5. Meatus (Nasal passages)

Fig. 4 Anatomy of the nasal cavity as seen from the front.

(after Jamieson, 1947)

typical and fixed formant-one of all French nasalized vowels (see Part V, Chapter 3).

As mentioned earlier (Part II, Chapter 1, Section 1.1.), several authors report movements of the lateral walls during the elevation of the velum (see also Part II, Chapter 2, Section 2.2.). This means that it is not only the degree of velopharyngeal coupling that is responsible for nasal resonance, but also variations in the volume of the nasopharynx caused by medial movements of the lateral walls.

1.3. The Nasal Cavities

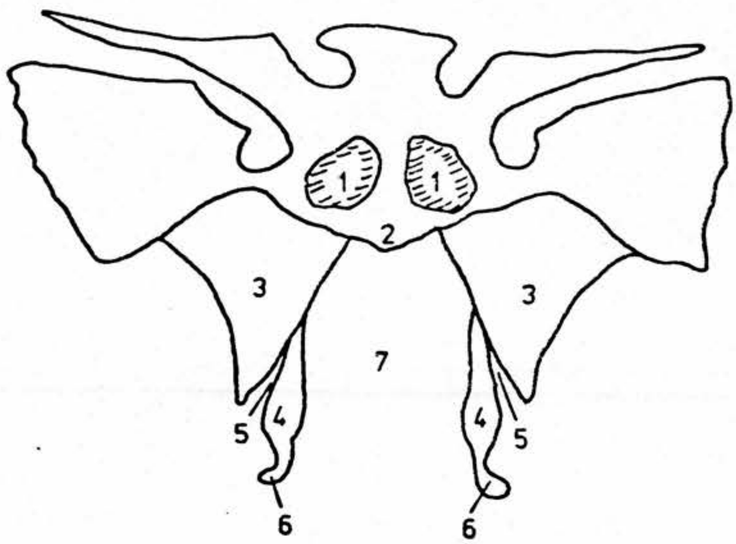
The best way to look at the nasal cavities is through coronal sections, because of the complex system of cavities shaped in this area (see Fig. 4). The nasal cavities communicate posteriorly with the nasopharynx by means of the posterior nares, i.e., two openings separated by the septum bone, and laterally, by the medial pterygoid plate. The nares are small openings located in the frontal wall of the nasopharynx. The septum bone divides the nasal cavities centrally in two halves or chambers, with the same general configuration on both sides. From the lateral side towards the septum (but not reaching it), the chambers have three shell-like plates situated one above the other with same space in between, and called the superior, the middle and the inferior conchae or turbinates. A schematic illustration of the anatomy of the nasal cavities is given in Fig. 4 The three hollows or recesses between the conchae are called the superior, middle and inferior meati, with the inferior meatus located below the inferior concha. The inferior meatus has the largest volume and the superior meatus the smallest. The superior meatus communicates with the sphenoidal sinuses and the middle meatus communicates with the ethmoidal cells, and the maxillar and frontal sinuses via the semilunar hiatus, a depression found below the superior concha anteriorly. The two anterior nares are located in the chambers at the frontal ending of the vomer bone, where the nasal cavities assume a simple round shape without the turbinates. The nasal channels are formed at that point by the cartilages of the septum which shape the tip of the nose. The vestibules of the nose are located in their lowest part, inside the nasal alae, and their outlets are the nostrils.

The nasal chambers have a rigid bony structure surrounding them, and they are not movable. The chambers are bounded at the highest point by the sphenoid bone, whose pterygoid plates constitute the lateral bony part of the nasal chambers. See Fig. 5 where a schematic illustration of the shape and parts of the sphenoid bone is given. The chambers are divided in two, medially, by the vomer bone or nasal septum. The floor of the chambers is formed by the superior surface of the palatine bone. The chambers are covered by a special membrane which also covers the internal part of the sinus and the sinus ducts to the nasal cavities.

Although the nasal chambers can be regarded as fixed cavities, nevertheless their volume is variable depending on the amount of mucus that fills them. The nasal passages can be completely blocked by the presence of the mucus or nasal catarrah.

Perfect symmetry between the two nasal chambers is rare in an adult, and in general, the asymmetry is due to deviation of the nasal septum.

One function of the nasal cavities is to locate the sense of olfaction. Although the ability to smell constitutes a protective defence, it is not at present very important and it is not rare to find adults who have completely lost their sense of smell. The



1. Sphenoid sinuses
2. Rostrum
3. Lateral pterygoid plate
4. Medial pterygoid plate
5. Pterygoid fossa
6. Hamulus
7. Nasopharynx

Fig. 5 Schematic diagram of the sphenoid bone as seen from the front.

(after Jamieson, 1947)

principal function of the nasal cavities is to provide an efficient system of air-conditioning (Negus 1957) before the air goes to the lungs. The intricate shape of the nasal cavities provides a good system for treating the air before it passes the larynx and goes to the lungs. The air is warmed, filtered and moistened by the nasal cavity system .

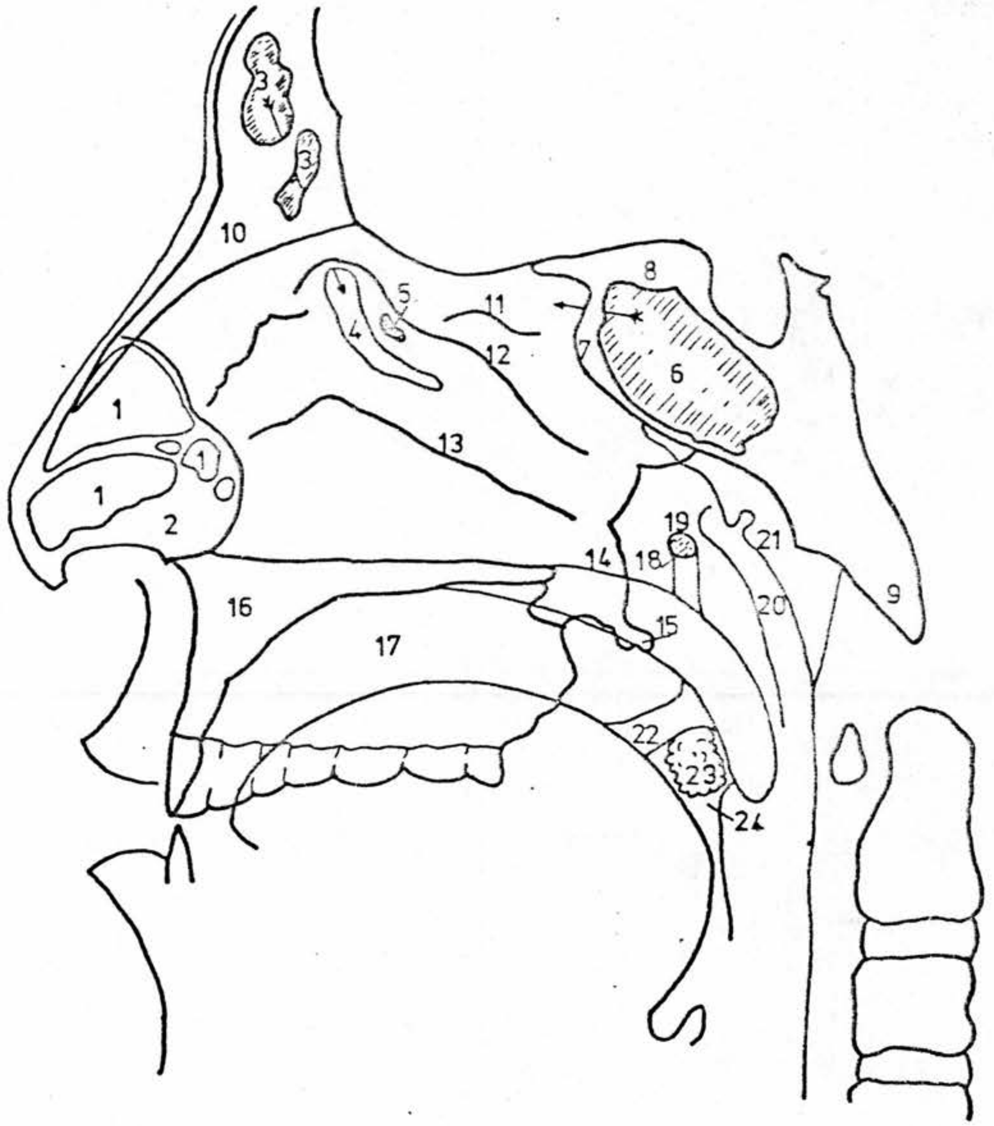
The nasal cavities have a function in speech contributing to the production of nasality. However, the acoustic characteristics of the nasal cavities are not yet fully understood (see Part V, Chapter 1, section 1.3.).

1.4. <u>The Sinuses</u>

The paranasal sinuses are recesses that drain into the nasal cavities (see Figs. 2, 4, 6). There are commonly four pairs of sinuses: frontal, maxillary, ethmoid and sphenoid. The sinuses develop only a little before puberty, but after that period they expand rapidly. They vary considerably in shape and size among individuals (Kaplan 1960: 225-230). Some individuals can have more than the traditional four pairs of sinuses. Kaplan (1960: 225) says that some individuals may have a palatine sinus, located in the orbital process of the palatine bone and in communication with either the sphenoid sinus or the ethmoid cells.

The frontal sinuses are located behind the superciliary arches of the eyebrows and separated by a septum bone. Some individuals present two pairs of sinuses interconnected in this area. Each sinus drains into the middle meatus, below the middle concha or turbinate where there is a depression in the wall called the semilunar hiatus (see Fig. 6).

The maxillary sinuses are located laterally in 'the lower half



1. Cartilages of septum
2. Vestibule of nose
3. Frontal sinuses
4. Semilunar hiatus
5. Anterior ethmoid sinus
6. Sphenoid sinus
7. Ala of vomer
8. Sphenoid bone
9. Basi-occipital bone
10. Frontal bone
11. Superior concha
12. Middle concha
13. Inferior concha
14. Medial pterygoid plate
15. Hamulus
16. Palatine bone
17. Alveolar process of maxilla
18. Eustachian tube
19. Tubal elevation
20. Salpingopharyngeus fold
21. Adenoids
22. Palatoglossal arch
23. Tonsil
24. Palatopharyngeal arch

Fig. 6 Schematic sagittal section through the nose, the mouth and the pharynx to show the anatomy of some structures involved in the production of nasality.

(after Jamieson, 1947)

of the nasal cavity, below the orbit and above the molar and premolar teeth' (Kaplan 1960: 224). Another name for them is the antrum of Highmore. The maxillary sinus is a pyramidal-shaped hollow in each side of the maxillary bone in the cheek area. They are the largest sinuses. The drainage into the middle meatus of the nasal cavities can be achieved by means of one or two canals situated slightly higher than the floor of the sinus.

The ethmoid sinuses are a 'labyrinth of thin-walled cavities' (Zemlin 1968: 251), also called air-cells. The air-cells look like a sieve, and the (Greek) word ethmoid means 'a sieve form'. Anatomically, they can be divided into three groups: the anterior, the middle and the posterior groups of cells. The anterior and middle groups drain into the middle meatus and the posterior into the superior meatus. The groups communicate ~~s~~ by one or two openings on each side. The ethmoidal air-cells are located in the 'labyrinth of the ethmoid bone, between the orbit of the eye and the nasal cavity and just below the cranial cavity' (Kaplan 1960: 223). The number of cells can vary between three and eighteen (ibid.).

The sphenoid sinuses are also large hollows. They are located in the front of the upper central part of the sphenoid bone. The sinuses are just above the posterior part of the nasal cavities and the anterior part of the nasopharynx. They communicate with the superior meatus of the nasal cavity, above the sup~~p~~erior turbinate, by means of a space called the spheno-ethmoidal recess of the nose (Kaplan 1960: 225).

The functions of the sinuses are: 1) to function as a 'heat insulator for surrounding cerebral structures' (Kaplan 1960: 223); 2) to allow large bones in the skull without adding too much weight; 3) to help to moisten the air in the respiratory process before it goes to the lungs; 4) to equalize the internal air pressure with the external air pressure; 5) possibly to contribute to nasal resonance.

Judson (1942: 114) reported the following estimated values of the volume of the sinuses: maxillary = 25 cm^3; sphenoid = 20 cm^3; frontal = 20 cm^3 and ethmoid = 7.5 cm^3.

The contribution of the sinuses as resonators is controversial (van Riper and Irwin 1958: 245). As a matter of fact, we know very little about them, and the statements about the resonating or non-resonating functions of the sinuses are highly speculative (see Part V, Chapter 1, section 1.5.). For example, White (1938) and others attributed the origin of voice to the sinuses. Such a naive statement requires no further comment (Greene 1964: 69, 75).

1.5. The Pillars of the Fauces

The oropharyngeal entrance is made up of two lateral arches called the pillars of the fauces. The anterior arch contains the palatoglossus muscle, and the posterior arch contains the palato-pharyngeus muscle. The arches originate from the sides of the soft palate, running downwards. The palatopharyngeal arch follows the side of the tongue down the pharynx on both sides. The palatopharyngeus muscle continues until it reaches the external side of the thyroid cartilage. See Fig. 7 .

The pillars of the fauces or isthmus faucium can be narrowed considerably by a sphincteric action of the muscles surrounding the opening. During speech, the entrance can be modified by the elevation of the back of the tongue, by the lowering of the velum or by a general contraction. This entrance is also known as the 'oral port'.

The pillars of the fauces can be approximated during phonation, giving the voice quality that Pike (1947: 22) describes as faucalized

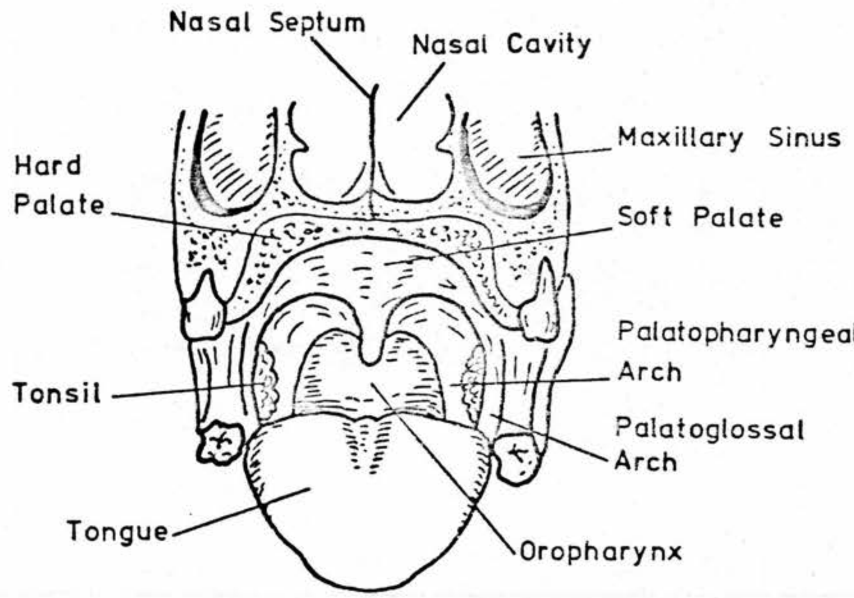


Fig. 7 Frontal section through the nose and mouth showing an oral view of the palate and the pillars of the fauces.

(from M.C.L. Greene, 1972: 57)

voice. The faucalization is the modification introduced by the tightning of the arches during speech. Pike observed that

> "The tenseness and harshness which come from the faucalization of the vocoids sometimes give a quality approximating that which comes from nasalization" (Pike 1947: 22).

However, he recognizes that nasalization is not an inherent product of faucalization. Some writers suggested that a cul-de-sac resonator may be set up by the contraction of the faucal pillars (for more information, see Part III, Chapter 2).

1.6. The Tonsils

The tonsils are a ring of lymphoid tissue surrounding the oropharyngeal and nasopharyngeal ports. They have a protective function against bacterial invasion into the body. The tonsils are also known as Waldeyer's ring (Zemlin 1968: 301-302). The ring is not continuous. It has three distinct parts: 1) the palatine tonsils, forming the lateral part of the ring; 2) the pharyngeal tonsils, forming the superior part of the ring; 3) the lingual tonsils, located in the inferior part of the ring (Kaplan 1960: 185-188).

The palatine tonsils, commonly refered to as 'tonsils', are located between the faucal pillars. When the tonsils have been removed, the space left is called tonsillar fossa. According to Fritzell (1969: 71), the removal of the tonsils does not affect speech. Laver (1975), however, pointed out that the tonsillar fossa may be used as a side chamber by some speakers (see Part III, Chapter 2).

The lingual tonsils cover most of the roof of the tongue starting from the lower end of the palatine tonsils.

The pharyngeal tonsils or 'adenoids' fill the fossa of

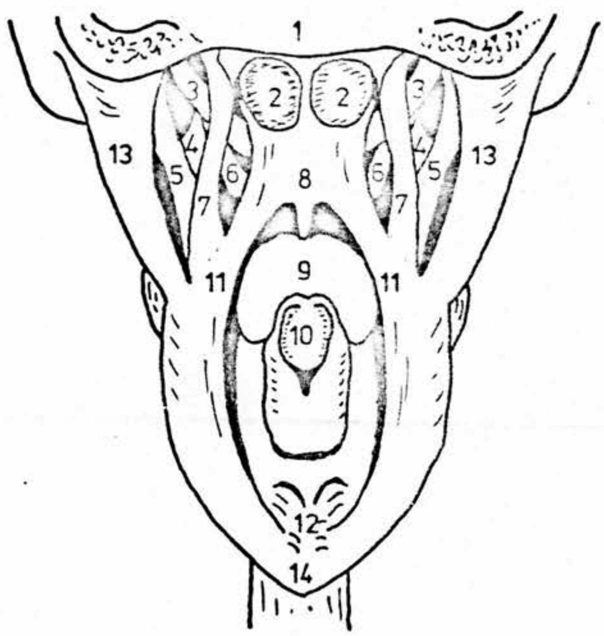
Rosemüller in the left upper part of the nasopharynx at the back wall. The adenoids grow until adolescence making the nasopharynx wall convex in that area, as mentioned earlier. In adults, the adenoids atrophy and present again a concave appearance. When the adenoids expand too much, they can close the two openings of the eustachian tube creating grave problems for the ear (Zemlin 1968: 375). The adenoids may play a role in the production of speech, either helping in velopharyngeal closure, noticeably in cases of speakers with a short velum and/or a deep pharynx, or obstructing the normal production of nasality (Zemlin 1968: 302; Greene 1964: 250-251). The term 'adenoidal voice' has been used for the latter case and means a denasalized quality of voice (Abercrombie 1967: 30; Laver 1975).

Chapter 2 : Velopharyngeal Muscles

2.1. Velopharyngeal Muscles

2.1.1. Introduction:

The velum and the nasopharynx contain 8 muscles that can be used in the production of speech. Six of them are inserted into the velum and two ran down into the pharyngeal wall without being attached directly to the velum. Of the two last muscles, one (salpingopharyngeus) can be regarded as a bifurcation of the palatopharyngeus muscle and is not consistently present in individuals, as Dickson and Dickson (1972) established by dissections (see also Harrington 1944: 329). The other muscle which is not attached to the velum is the stylopharyngeus muscle. It originates in the styloid process of the temporal bone, running vertically downwards via the lateral pharyngeal



1. Base of skull
2. Nasal cavity
3. Levator palatini
4. Stylopharyngeus
5. Stylohyoid
6. Tensor palatini
7. Salpingopharyngeus
8. Velum
9. Tongue
10. Epiglottis
11. Palatopharyngeus
12. Posterior cricoarytenoid
13. Superior constrictor
14. Oesophagus

Fig. 8 Schematic representation of a dissection of the pharynx, with a posterior view, to show the location of the velopharyngeal muscles in relation to the velum, the tongue, the pharynx and the larynx.

wall, until it reaches the thyroid cartilage. Both the salpingopharyngeus and the stylopharyngeus muscles have the function of drawing the pharynx up (Zemlin 1968: 563-564). Dickson and Dickson (1972: 379) concluded that the 'salpingopharyngeus probably has little, if any, functional significance'. Greene attributes some importance to the action of these muscles:

> "The stylopharyngeus and salpingopharyngeus muscles reinforce the lateral pharyngeal walls and upon contraction raise and shorten them, decreasing the transverse and longitudinal measurements of the pharynx. At the same time, by reason of their attachment to the larynx, they assist in elevation of the larynx. This takes place in deglutition and to a lesser extent in speech" (Greene 1964: 64).

The other 6 muscles attached to the velum are: tensor palatini, levator palatini, superior constrictor, palatoglossus, palatopharyngeus and uvular muscle. The uvular muscle is the only one that is not paired.

There is not complete agreement in the literature about which muscles act upon the soft palate in the production of speech. Fritzell (1969: 73) recognizes 5, leaving the uvular muscle out; Kaplan (1960: 188) also recognizes 5, but he leaves the superior constrictor out; in textbooks on phonetics, it is common to find mention of only 4: tensor, levator, palatoglossus and palatopharyngeus muscles (Brosnahan and Malmberg 1970: 39). These muscles are traditionally classified in three groups: 1) the elevators (levator and uvular muscles); 2) the depressor-relaxers (palatoglossus and palatopharyngeus muscles); 3) the elevator-tensor (tensor muscle). This classification is not very consistent nowadays after EMG studies of the function of these muscles. Fritzell (1969: 69) summed up the divergent issues about the activity of the velopharyngeal muscles during speech, and concluded:

"The discrete function of the individual muscles that control the movements of the palate is not altogether clear. Everyone seems to agree on the crucial importance of the levator and on the participation of the superior constrictor in accomplishing velopharyngeal closure, and no one has disputed the velum-lowering function of the palatoglossus muscles. The role of the tensor in speech, however, is doubtful, and the contribution of the palatopharyngeus muscle to velopharyngeal closure remains hypothetical".

Fritzell (1969: 56) found out also that the EMG curve of the levator has a striking similarity to the curve of the mechanical movements of the velum (see Fig. 12).

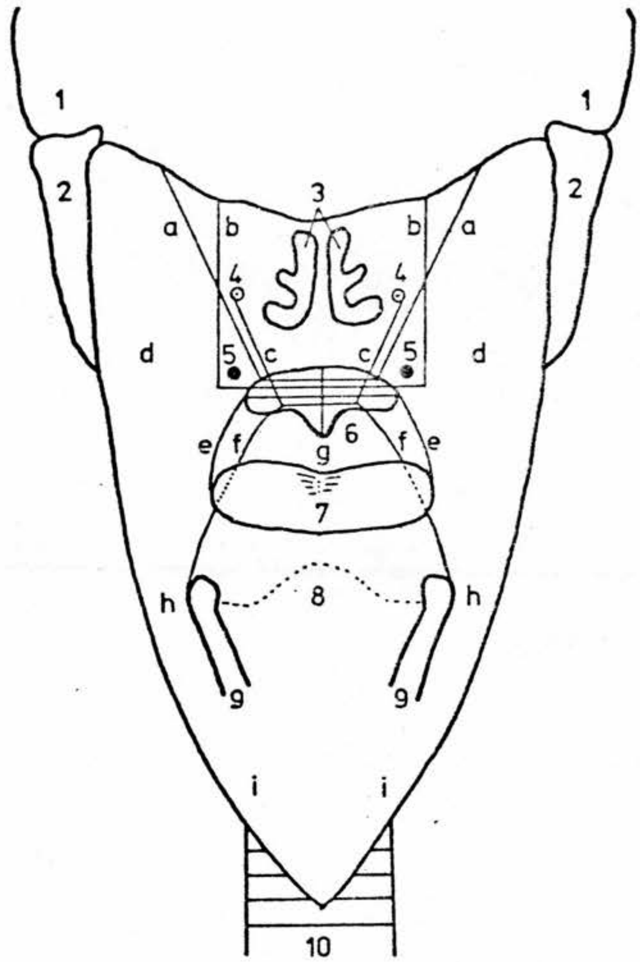
It is still an open question as to whether velopharyngeal closure is accomplished by a sphincteric or by a sling action of the muscles involved. This problem will be discussed in section 2.2. of the present chapter. We will now discuss each muscle separately.

2.1.2. Musculus Levator Veli Palatini:

Origin: the levator originates from a small prominence of the basicranium, i.e., from the petrous part of the temporal bone and the medial end of the canalis caroticus or eustachian tube (Fritzell 1969: 15; Zemlin 1968: 297-298; Kaplan 1960: 189). See Figures 8 and 9 for location and schematic illustration of the structures discussed in this section.

Course: the levator courses along the inferior and posterior part of the eustachian tube making up the front part of the lateral pharyngeal wall in the nasopharynx in both sides of the posterior nares or choanae. It runs medially and frontally.

Insertion: the levator inserts into the velum in a direct line with the velum in a raised position (Dickson and Dickson 1972: 378). It extends from the palatal aponeuroris to the uvula with a spreading



1. Sphenoid bone	a. Levator palatini m.
2. Mandible	b. Tensor palatini m.
3. Nasal cavities	c. Salpingopharyngeus m.
4. Torus tubarius	d. Superior constrictor m.
5. Hamulus	e. Palatoglossus m.
6. Isthmus faucium	f. Palatopharyngeus m.
7. Tongue	g. Azygos uvulae m.
8. Epiglottis	h. Middle constrictor m.
9. Thyroid cartilage	i. Inferior constrictor m.
10. Trachea	

Fig. 9 Schematic diagram illustrating the location of the palatal musculature and adjacent structures.

of its fibres into the velum.

Characteristics: the levator palatini is a slender muscle, 'pencil-thick' (Kaplan 1960: 189), of uniform dimension along its course, but spreading inside the velum. The bulk of the velum is made up of the levator muscle. It courses inside the velum above other muscles, forming the superior surface of the soft palate. It interlaces with other muscles, particularly with the palatopharyngeus (Fritzell 1969: 15).

Function: the levator palatini is the most important muscle in the velopharyngeal closure. By contraction, the levator palatini moves the mid part of the velum upwards and backwards. This movement can be vigorous and can make the posterior part of the velum compress and bulge upwards, so that the velum acquires a knee-shaped form during the closure of the nasal port. Fritzell (1969: 36) registered higher EMG activity of this muscle during the production of oral sounds than during the production of nasal sounds. The levator activity increased proportionally from [a] over [i] to [u]. Fritzell (1969: 56, 75) found a striking similitude between the levator activity curve and the curve of the movements of the velum, as mentioned earlier (see Fig. 12). He drew the velic movement curve by reading the position of the velum along a reference line at equal intervals of time from a cineradiographic film. He says:

> "When these measurements of velar (sic) displacement were plotted on the EMG record, a striking similarity was found between the levator envelopes and the velar movements. The palatoglossus activity demonstrated a close relationship to the descent of the velum, as well as to the production of the [k], [g] and [ŋ] -sounds" (Fritzell 1969: 75).

Fritzell (1969: 74) observed also that with initial nasals, a low to moderate degree of levator EMG activity was recorded preceding the sound. It probably means that the nasals were articulated not with the velum in rest position but slightly raised (Moll and Shriner 1967: 66).

The levator palatini influences the oropharyngeal isthmus by lifting the soft palate (Kaplan 1960: 189). It also assists in the process of moving the eustachian tube forward and opening it, and because of this, Dickson and Dickson (1972: 379) suggest that the levator is one of the muscles responsible for movements of the lateral pharyngeal walls during speech. They cite other writers who also suggest this function, for example, Strong (1943, 1949); Bosma (1953); Bloomer (1953); Moss (1958) and Harrington (1944).

2.1.3. Musculus Tensor Veli Palatini:

Origin: the tensor palatini originates at the base of the skull, in the inferior surface of the sphenoid bone, one the medial pterygoid plate and on the base of the auditory tube along the cartilaginous and membranous walls of the eustachian tube, well above the opening leading to the nasopharynx (Fritzell 1969: 12; Zemlin 1968: 299; Dickson and Dickson 1972: 378, 380). See Fig. 9 .

Course: the tensor descends almost vertically along the medial pterygoid platé whose inferior ending has a hook-like shape, called the pterygoid hamulus. The fibres of the tensor acquire a tendon shape and wind around the hamulus and insert into the velum horizontally. The tensor is located laterally and anteriorly to the levator (Kaplan 1960: 189).

Insertion: the tensor is inserted into the velum medially in a vertical plane and anteriorly in a horizontal plane. In the velum, it is located below the levator. The palatal aponeurosis of the soft palate is made up mainly of fibres of the tensor.

Characteristics: this muscle is flat and triangular in shape, with a ribbon-like mass or tendon. A more accurate look at the structure of this muscle indicates a more complex structuring than the simple view of a tendon muscle stretching the soft palate. Concerning this, Fritzell says:

> "The structure of the tensor is complex, and various researchers distinguish 2 or 3 portions or layers, with different origins and insertions. These portions may have different functions and the recordings made might have been obtained from different portions of the tensor" (Fritzell 1969: 48).

In the passage above, Fritzell was discussing some inconsistent findings of the tensor activity among his subjects. Some fibres of the tensor interlace with fibres of other muscles attached to the palatine aponeurosis.

Function: contrary to the belief set out in some early textbooks, recent investigations of the activity of this muscle have shown that its function is not to elevate the soft palate. No elevator function of this muscle has been found in EMG records made during speech. On the contrary, as Fritzell points out:

> "Most modern researchers agree that, when tensor muscles contract, they depress the anterior part of the velum. This is caused by the lower position of the hamulus in relation to the insertion of the tensor into the soft palate"(Fritzell 1969: 14).

Fletcher, in a study of maturation of the speech mechanism, observes:

> "The spatial relation of the palate to its extrinsic musculature also changes during (postnatal) development. The palate descends in relation to the origin of the levator veli palatini muscle, which is on a small prominence of the basicranium at the medial end of the eustachian tube. Accordingly, because the palate occupies a relatively high position within the pharynx, this muscle is actually a

tensor of the palate within the infant pharynx and only later becomes a palatal elevator. The descent of the hard palate is also relatively greater than that of the hamular processes of the pterygoid plates; therefore, the tensor veli palatini which in infancy is a depressor of the palate, becomes, as its name indicates, a palatal tensor" (Fletcher 1973: 167).

In the adult, when the tensor is contracted it forces the soft palate laterally. This action flattens, stretches and lowers slightly the anterior part of the velum. The horizontal stretching from side to side makes the soft palate taut (see illustration in Moley 1957: 292).

Van Riper and Irwin (1958: 382) recognize some importance in the tensor activity during speech: 'its action is important for all of the sounds of English except the three nasals, for which it must relax'. Fritzell found inconsistent findings of tensor activity during speech and concluded that its function in speech is doubtful (Fritzell 1969: 14-15). Greene (1964: 59) agrees with Fritzell and also agrees with the procedure of sacrificing it 'in cleft palate operations when the hamulus is fractured in order to produce longer backward reaching palatal flaps'.

Wilms (1953) suggested a combined action of the tensor and the palatoglossus during nasal sounds. In Fritzell's (1969) study, this relationship was not found.

A very important function of the tensor, nevertheless, is to open the eustachian tube for ventilation of the middle ear (Fritzell 1969: 72; Dickson and Dickson 1972: 380).

2.1.4. Musculus Constrictor Pharyngis Superior:

Origin and parts: the superior constrictor can be regarded as made up of 4 distinct parts: 1) the pterygopharyngeal part attached to the sphenoid bone on the lower part of the pterygoid plate and hamular process; 2) the buccopharyngeal part whose origin is the pterygo-mandibular raphe; 3) the mylopharyngeal part attached to the mandible from inside at the alveolar process of the lower jaw; 4) the glossopharyngeal part inserted into the tongue (Kaplan 1960: 204; Zemlin 1968: 307). See Fig. 9 .

Course: the superior constrictor is the cover of the upper pharynx, coating the nasopharynx laterally. The fibres run almost horizontally from both sides and fuse at the back forming the upper posterior pharyngeal wall. The fibres radiate assuming a fan-like shape in their posterior part.

Insertion: the superior constrictor inserts into the median raphe and pharyngeal spine of the occipital bone (van Riper and Irwin 1958: 382). It inserts into the tongue (Fritzell 1969: 17), and into the pterygo-mandibular raphe (Fritzell 1969: 17). Fibres of the superior constrictor are also inserted into the velum, where they divide into two and surround the fibres of the levator palatini in the majority of adults (Dickson and Dickson 1972: 375).

Characteristics: Fritzell (1969: 47) made EMG recordings of this muscle and observed that the superior constrictor muscle is the most difficult muscle to locate in EMG experiments. The superior constrictor is a broad quadrilateral band open anteriorly and horizontally placed, looking like an incomplete loop. This muscle does not reach the base of the skull. The superior constrictor is overlapped by fibres of the medial constrictor muscle. Dickson and Dickson (1972: 377) found fibres of the superior constrictor interwined with or penetrated into the fibres of the levator. Zemlin observes:

> "The portion that arises from the pterygoid plate and its hamular process is sometimes designated as a separate muscle called pterygopharyngeus, and fibers from it have been consistently found to blend with those of the palatopharyngeus

> muscle. This finding has important implications with respect to the velopharyngeal mechanism" (Zemlin 1968: 307).

One implication, of course, is the contribution towards a sphincteric action during velopharyngeal closure (see Part II, Chapter 2, section 2.2.).

Function: when the superior constrictor contracts it squeezes and narrows the nasopharynx. The constrictive action of this muscle assists also in the closure of the nasal port as described by Fritzell:

> "When the superior constrictor contracts, the upper pharynx is narrowed. This constriction is no doubt most effective in the lateral pharyngeal walls, but it also gives rise to a slight forward bulging of the posterior pharyngeal wall. In some subjects this takes the form of a transversal fold, 'Passavant's ridge'. The palatal insertion exerts a backward pull on the soft palate" (Fritzell 1969: 18; see also Kaplan 1960: 190).

The superior constrictor is active during oral sounds and shows weak or no activity during nasal sounds (Fritzell 1969: 32). As pointed out earlier, the superior constrictor muscle presents an EMG recording of the same pattern as the levator palatini muscle (Fritzell 1969: 36-40, 48, 74). The EMG activity is increased gradually over the range of sounds from [a] to [i] to [u] (Fritzell 1969: 36-40). Greene (1964: 63) suggests that there is a synergistic action between the superior constrictor in conjunction with the palatopharyngeus muscle, and to a lesser degree a synergistic action between the superior constrictor and the levator palatini muscle. Van Riper and Irwin (1958: 382) state that the superior constrictor 'has been held to contract in unison with the tensor and levator in closing off the nasal from the oral passageway'. Fritzell (1969) did not find a synergistic action between the superior constrictor and the tensor palatini. The interaction between the superior constrictor and the palatopharyngeus is highly probable however, since it is not easy to separate the two muscles where they converge in the pharynx (Bosma and Fletcher 1962; Fritzell 1969: 18).

2.1.5. Musculus Uvulae (Azygos Muscle):

Origin: the uvular muscle has its origin in the back of the hard palate on the posterior nasal spine of the palatine bone and in the palatine aponeurosis. See Fig. 9.

Course: the uvular muscle runs horizontally and posteriorly when the soft palate is raised, forming the mid-line structure of the velum. It overlies the other muscles of the soft palate. The uvular muscle starts frequently as a paired muscle made up two slender slips which fuse together before insertion into the uvula. It has been reported that some fibres of the palatopharyngeus muscle pass over it posteriorly (Voth 1961).

Insertion: the uvular muscle is inserted into the palatine aponeurosis and into the uvula.

Characteristics: the uvular muscle has a cone-like shape (Kaplan 1960: 184). This muscle may be sometimes unpaired and inside the uvula the two slender slips are always fused.

Function: when the uvular muscle contracts, it shortens the uvula and brings it upwards and backwards (Kaplan 1960: 184; Zemlin 1968: 300). Fritzell (1969: 18) observed that the functional significance of this muscle (and of the uvula) is doubtful. Kaplan (1960: 184), however, has a completely different opinion about them, saying that the uvula is a 'highly functional structure' from the physiological point of view. He lists the following functions of the uvula: 1) it is important in swallowing, assisting in directing the food downwards;

2) it helps in preventing middle ear diseases together with other palatal structures which maintain the eustachian tube opening area clean; 3) it massages and moistens the posterior pharynx; 4) it aids the removal of material from the pharynx and nasopharynx. Kaplan recognizes also two functions related to speech production: 5) it helps to prevent excessive nasality and is active in velopharyngeal closure; 6) it is used to produce the uvular trill.

About the speech significance of the uvular muscle, Fritzell (1969: 18) says laconically: 'there is no information on its possible participation in speech'. Van Riper and Irwin (1958: 381) share the same opinion as Fritzell. They also state that the uvula can be removed without leaving speech problems. Kaplan (1960: 185) shares another view here saying that 'uvular resection (or staphylectomy) may lead to disturbances of speech and deglutition'.

2.1.6. Musculus Palatoglossus:

Origin: the palatoglossus muscles arise from the longitudinal and superficial fibres of the styloglossus and hyoglossus muscles in the dorsum of the tongue (Zemlin 1968: 281). In their origin, the fibres of the palatoglossus are blended with the fibres of the stylo-glossus and hyoglossus muscles (van Riper and Irwin 1958: 379; Kaplan 1960: 253). See Fig. 9 .

Course: the course of the palatoglossus is upwards, slightly backwards and laterally. The fibres from both sides are intermixed in the soft palate, forming the lower surface of the velum in its anterior part. The palatoglossus makes up the glossopalatine arch anteriorly to the tonsils (see Part II, Chapter 1, section 1.5.).

Insertion: this muscle is inserted into the velum inferiorly and anteriorly at the lower part of the palatine aponeurosis.

Characteristics: the palatoglossus is a small, thin muscle

(1.5 mm x 3 mm, Fritzell 1969: 15). It has an open circular course with a sphincteric-like action when it contracts. Kaplan (1960: 190) quotes Diamond (1952) saying that

> "Diamond states that the fibers (of the palatoglossus) bend transversely to enter the medium septum of the tongue, so that they aid forming a more or less circular sphincter. These fibers are then said to continue as transverse intrinsic tongue fibers".

This is the reason by which this muscle can also be classified as an extrinsic muscle of the tongue: the glossopalatinus muscle.

Function: van Riper and Irwin describe the two major functions of this muscle saying that

> "This muscle, sometimes called the glossopalatinus, like the stylohyoid lifts the back portion of the tongue if the soft palate is fixed. When, on the contrary, the rear of the tongue is anchored by the fixation of the hyoid and the contraction of the hyoglossus, the palatoglossus will pull down on the velum. It thus has two functions, depending upon whether the origin or insertion point is anchored" (van Riper and Irwin 1958: 379; see also Kaplan 1960: 281; Zemlin 1968: 300 and Fritzell 1969: 15, 56, 74).

When the palatoglossus pulls down the velum, the soft palate is drawn forward. When this muscle contracts, the fauces are constricted too (Kaplan 1960: 190; Zemlin 1968: 300). Greene (1964: 59) attributes an important function to the palatoglossus muscle in speech. Bell-Berti (1971), quoted by MacNeilage (1972: 22), in an EMG investigation, did not observe the action of the palatoglossus lowering the velum, instead she observed its activity in raising the back of the tongue in velar sounds.

Fritzell (1969), in an extensive EMG study of the activity of this muscle, concluded that it is very important in speech and essential to pulling down the velum, since this is not achieved by the force of gravity. He observed that 'fall of the velar (sic) movement curve almost always corresponded to a rise of the palatoglossus envelope' (Fritzell 1969: 56). Fritzell (1969: 40) also observed some activity of this muscle in final vowels at the end of utterances, the activity being higher for [u] than for [a] and [i] . The palatoglossus is necessary to pull down the soft palate, and can assist in raising the back of the tongue.

2.1.7. Musculus Palatopharyngeus:

Origin: the palatopharyngeus muscle has a wide origin with the lowest attachments fixed onto the posterior border of the thyroid cartilage in the larynx. At that point, the palatoglossus is blended with the stylopharyngeus muscle. The palatopharyngeus muscle is also attached to the back and lower lateral walls of the pharynx (Fritzell 1969: 16). See Fig. 9 .

Course: Its fibres, which are oriented vertically, converge towards the velum. The fibres which are spread out in the lower pharynx are concentrated in the higher part of the pharynx, forming two slender slips that constitute the palatopharyngeal arch (van Riper and Irwin 1958: 382). They then insert into the velum.

Insertion: the insertion is into the velum from both sides, laterally and posteriorly. The descending fibres of the levator divide the fibres of the palatopharyngeus muscles into two strands (Fritzell 1969: 16).

Characteristics: this muscle spreads out in a thin sheet on the pharynx, and is long and thin along its course (van Riper and Irwin 1958: 382; Kaplan 1960: 190). Fritzell (1969: 16) points out that the palatopharyngeus muscle is considerably larger than the palatoglossus. The palatopharyngeus is a complex muscle. It blends with fibres of the stylopharyngeus muscles, with fibres of the superior constrictor, and a deviation of it passes above and laterally along the velum ending in an attachment on the auditory tube. This last section is usually considered as a distinct muscle called the salpingopharyngeus muscle (Kaplan 1960: 190; Fritzell 1969: 16). Because of its attachment to the thyroid cartilage, as Zemlin (1968: 300) observes, it can be regarded as an extrinsic muscle of the larynx.

Function: the palatopharyngeus muscle has a complex range of functions when it contracts. The posterior pillars are stretched, brought close, almost together at mid line, narrowing the oropharyngeal port when it contracts. This narrowing is important to set the oral cavity as a side chamber resonator in the production of nasalized sounds (Greene 1964: 65). The palatopharyngeus muscle also pulls the soft palate down in a mid to posterior direction and, therefore, it can be regarded as a palatal depressor muscle in the velopharyngeal mechanism (Kaplan 1960: 190). The palatopharyngeus muscle assists in velopharyngeal closure by bringing the lateral walls of the pharynx towards each other medially. This action constricts and lifts the pharynx slightly. Fritzell (1969: 70) observed that, in the production of [a], the pharyngeal walls were constricted by the action of the palatopharyngeus muscle. Because of its attachment to the thyroid cartilage, when this muscle contracts, it lifts the larynx and the pharynx (Kaplan 1960: 190; Zemlin 1968: 564-565; Fritzell 1969: 16-17). Zemlin comments:

> "Because of the semicircular course of the fibers, this muscle can also act as a sphincter to lower the palate and decrease the distance between the posterior faucial pillars, an action that is quite vigorous during swallowing and gagging, when the muscles nearly meet at the mid-line. This muscle may also be quite properly regarded as an extrinsic muscle of the larynx,

since its contraction may raise the larynx or tilt the thyroid cartilage forward. Elevation of the larynx occurs during phonation at the extreme high end of the pitch range" (Zemlin 1968: 300).

The palatopharyngeus muscles have been said to assist in velopharyngeal closure, but Fritzell (1969: 70) found no consistent results in his EMG investigations. MacNeilage (1972: 22) based on Fritzell (1969) and Bell-Berti (1971) summed up the function of the palatopharyngeus muscle during speech saying that it is active in the production of oral sounds and inactive in the production of nasal sounds. Fritzell recognizes very little relationship between palatopharyngeus activity and speech production:

> "When the palatopharyngeus muscle was active in speech it seemed to be involved mainly in the production of oral speech sounds, but less consistently than the levator" (Fritzell 1969: 74).

The palatopharyngeus muscle is particularly important in swallowing.

2.2. The Velopharyngeal Sphincter

We do not know much about the dynamics of velopharyngeal muscular activity involved in the process of shutting and opening the nasal port. Many details of this activity are still to be clarified.

In physiological terms, an opening may be closed by a sling or by a sphincteric control. Van Riper and Irwin explain what sling and sphincteric mean, as follows:

> "By sling is meant an arrangement of muscles from two or more points of suspension whose contractions will raise or support an object slung between them...
> By sphincter is meant a drawstring-like arrangement in which a complete circle of muscles contracts and narrows

the lumen of a tube" (van Riper and Irwin 1958: 389).

The muscles with a sphincteric characteristic produce a closure by a process called 'sphincteric action'; the muscles with a sling characteristic produce a closure by a process called 'sling action' or 'valvular action'. A sphincteric action is typical of the lips and a sling action is typical of the epiglottis.

The two types of muscular action have been attributed to the velopharyngeal mechanism, with a great deal of discussion and without conclusive results. Van Riper and Irwin suggested an intermediate position saying that

> "The action (closing the nasal port), then, seems to be a combination of valvular movement on the part of the soft palate and sphincter movement by the superior constrictor and its related fibers" (Van Riper and Irwin 1958: 391).

According to them, the main movement of the velum is performed by a valvular action, but the lateral and posterior pharyngeal walls assist in the closure to complete the seal. They also point out that in speech, the movements are too fast and too great an extent to be controlled quickly and surely by a sphincteric action alone (van Riper and Irwin 1958: 390). They conclude the discussion saying that

> "In rapid speech, the sphincteric action may be somewhat fixed, with the velar valve actually doing the opening and closing" (van Riper and Irwin 1958: 391).

Podvinec (1952) supports the point of view against the interpretation of a sphincteric action for the velic movements in speech. Fritzell (1969: 11) and Björk (1961) found the sphincteric action of the velum insignificant, and recognized the velic movement as a valvular action.

Another controversial problem related to this discussion is concerned with the structures involved in a total or partial sphincteric activity in velopharyngeal closure. It seems to be generally agreed that the superior constrictor must play a very important role in this activity. But the participation of other muscles has been an object of controversy and discussion. For example, the participation of the salpingopharyngeus muscle has been suggested by Harrington (1944), the participation of the palatopharyngeus by Bloomer (1953), and the action of the levator moving the auditory tube opening medially by Dickson and Dickson (1972). The presence of a forward movement of the posterior pharyngeal wall is another point of controversy, and it will be discussed separately in the next section (2.3.).

Zemlin (1968: 300) observes that the palatopharyngeus and the palatoglossus muscles present a sphincteric action shortening the isthmus of the fauces and lowering the soft palate.

The medial movement of the lateral pharyngeal walls has been found to be inconsistent among individuals, as reported by Taub (1966) and Zwitman et al. (1974: 366, 371). Harrington says:

> "Mesial movement occur over a considerable vertical extent. Movement may be greater at a lower level than at its highest position. The amount of mesial movement is directly related to the extent of velar elevation. Greatest extent of mesial movement appears to occur in the area overlying the salpingopharyngeus muscle" (Harrington 1944: 344).

According to Calnan's (1955: 15) observations, the lateral walls move inwards approximately over one third of the total area of the nasopharynx. The sphincteric action is produced at the horizontal level of the soft palate and above it by the displacement of the lateral walls of the nasopharynx. Below the horizontal level of the soft palate, there is no sphincteric activity (Fletcher 1973: 166). Zagzebski (1975) rediscussed the problem recently, and investigated the displacement of the lateral pharyngeal wall at two levels simultaneously: at the level of the velopharyngeal closure and at the level of the mid oropharynx region. He used an ultrasound technique and observed, at the first level, that

> "Lateral pharyngeal wall behavior monitored at this level with ultrasound is in agreement with the hypothesis that mesial movements are part of the normal valving mechanism of the velopharyngeal port. Ultrasound records indicate that the superior wall of the oropharynx are drawn mesially for stop consonants and vowels. Displacements were also mesial but reduced for nasal speech samples embedded in a carrier phrase" (Zagzebski 1975: 315).

And at the second level:

> "Pharyngeal wall motion at the midoropharynx level can be characterized as vowel-type dependent. Displacements at this level tend to yield an expanded pharyngeal volume during high vowels and a reduced volume during low vowel phonations. The position of the lower walls during consonants is dependent on the vowel environment; that is, the vowels carry the consonants at this level in the pharynx. In contrast, results with the high transducer placement indicate that the consonants carry the vowels for pharyngeal wall motion at the level of velopharyngeal closure" (Zagzebski 1975: 315).

Zagzebski (1975: 316) measured the extent of the mesial displacement of the lateral pharyngeal wall at the level of velic closure, and said that the displacement can be as large as 10 - 12 mm during speech. He attributed the mesial movements principally to the action of the superior constrictor muscles, and partly to muscular constriction of the levator.

Zwitman et al. (1974) investigated the velopharyngeal closure in 34 subjects with normal voice, with the help of an endoscope through the mouth. They took pictures and from the analysis of these, they came to the conclusion that individuals have a characteristic mode of performing velopharyngeal closure, and that the individual characteristics could be classified into four typical categories. These categories represent features of individual speech production, and it is not common for a single individual to use different categories (Zwitman et al. 1974: 371). The classificatory criteria used concerned the behavior of the lateral pharyngeal walls. They describe each category as follows:

> "Category 1: lateral walls move medially and fuse, resulting in a purse-string closure as the velum touches the approximated section of the lateral walls.
>
> Category 2 : lateral walls almost approximate, with the velum contacting the lateral walls and partly occluding the space between them. A small medial opening is observed in some cases.
>
> Category 3 : lateral walls move medially, filling the lateral pharyngeal gutters and fusing with the raised velum as it contacts the posterior wall.
>
> Category 4 : lateral walls move slightly or not at all. Velum touches posterior wall at midline and lateral openings are observed during phonation" (Zwitman et al. 1974: 368).

In Fig. 10 some schematic diagrams are offered to illustrate the four categories as described and illustrated with pictures by Zwitman et al. (1974). Velopharyngeal closure starts from the rest position of the velum (as in a) and is constricted either by the action of the rising velum alone (as in b), or by simultaneous rising of the velum and medial contraction of the lateral walls (as in c). From the position described in (b), the velum contacts the posterior pharyngeal wall, but the lateral walls do not move medially, and a small gap in

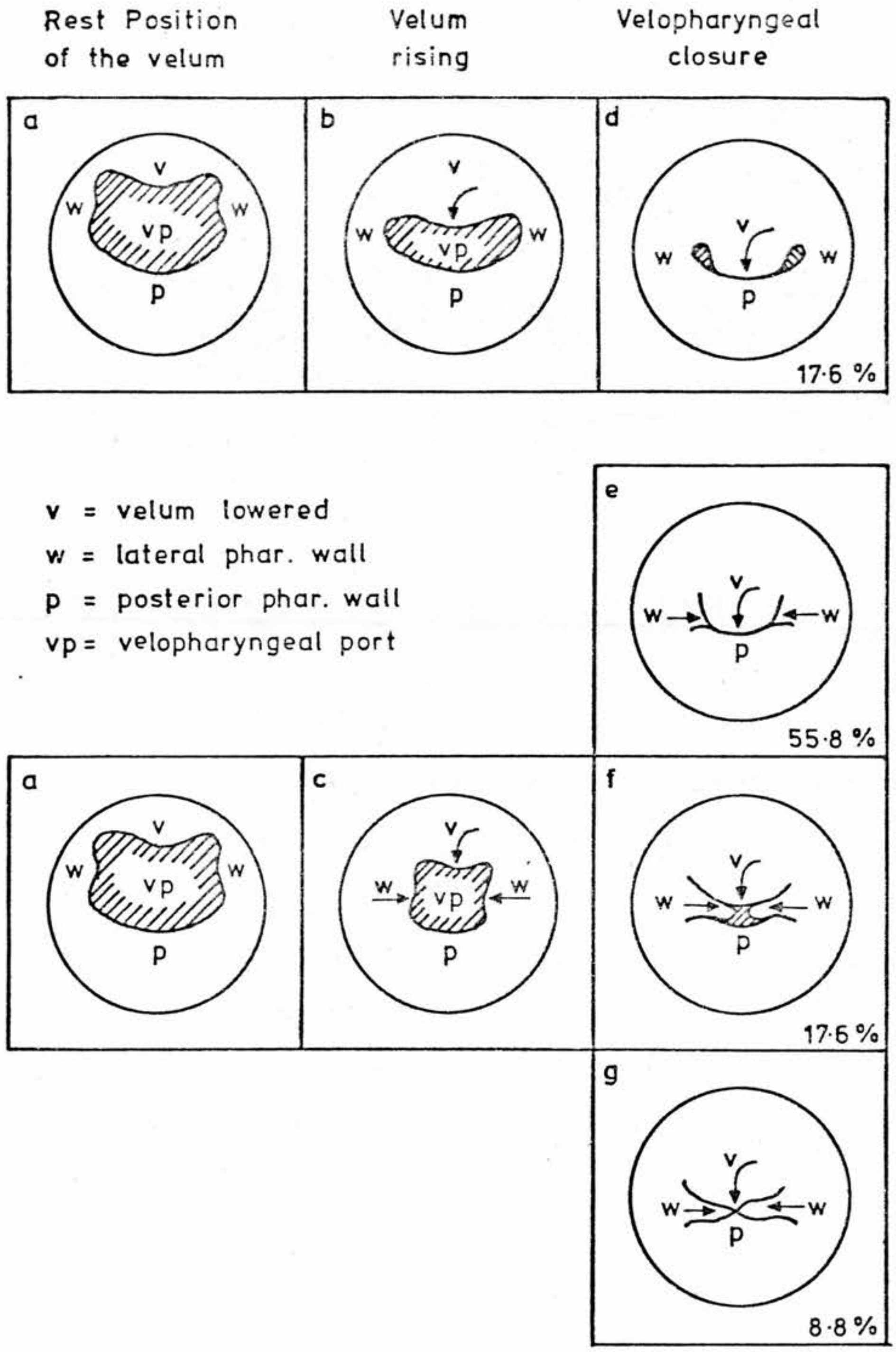


Fig. 10 Schematic diagrams based on endoscopic pictures of the nasal port, from below, to show four types of velopharyngeal closure during phonation of normal speakers, as described and illustrated by Zwitman et al. (1974: 366-372). The average percentage is out of 34 subjects.

both sides is observed (as in d). From the position described in (c), three alternative modes of closure are possible: 1) the velum contacts the posterior pharyngeal wall and the lateral walls contact medially, so that no gap is left. This can be interpreted as a sphincteric action by the velum (as in e); 2) the lateral wall may advance more quickly than the rising velum, so that the velum is compressed against the lateral walls at the back, and the lateral walls contact the posterior pharyngeal wall. Because the lateral walls do not touch one another medially, a small gap results in this mode of velopharyngeal closure (as in f). This can also be regarded as a sphincteric action by the velum; 3) the rising velum, the lateral walls and the posterior wall join together to produce a complete closure with a sphincteric action of the muscles involved (as in g).

The results found by Zwitman et al. (1974) for the statistical averages of occurrence of each category among the subjects investigated are presented in Fig. 10 as well. As one can see, the most common mode (with 55.8 %) is represented by (e) of the category 3, with a combined valvular and sphincteric action of the muscular structures involved in this process. The less common mode (used by only 8.8 % of the subjects investigated) is represented by (g) of the category 1, with the typical sphincteric action. 35.2 % present an incomplete closure in their velopharyngeal action closing the nasal port in normal speech, and 64.6 % present a complete closure as a habitual process of making velopharyngeal closure in speech.

2.3. Passavant's Cushion

Until the beginning of the 18th century, the velopharyngeal closure had been accepted as being accomplished by the movements of the velum alone. In 1836, Hilton reported medial movements of the lateral pharyngeal walls, observing the velopharyngeal closure directly in a speaker with a facial defect. In 1863, working with cleft palate speakers, Passavant noticed anterior movements of the posterior pharyngeal wall in velopharyngeal closure during speech. This movement of the posterior pharyngeal wall produces a muscular bulge, formed at the level of the anterior arch of the Atlas vertebra, which is known as Passavant's cushion (or pad, ridge, bulge, bar, etc.).

The muscular bulging is caused by contraction of the superior constrictor muscle, particularly by its pterygopharyngeal portion, and by the palatopharyngeus muscle (Last 1960; Kaplan 1960: 179; Greene 1964: 59; Zemlin 1968: 308; Dickson and Dickson 1972: 379). Harrington (1944) and Dickson and Dickson (1972: 373) pointed out that the insertion of the superior constrictor into the velum is particularly suitable for producing the anterior movement of the posterior pharyngeal wall when it contracts. According to Kaplan, the superior constrictor may be used to adapt the bulging to complete the velopharyngeal closure. He says:

> "In speech, the superior constrictor may possibly help to elevate the ridge of Passavant, narrowing the nasopharynx anteroposteriorly and laterally. Cessation of speech often is attended by a sensation of relaxation in the posterior pharyngeal wall" (Kaplan 1960: 208).

Passavant's discovery has not been accepted without discussion. On the contrary, the research in this area has caused great controversy. The problem is not the presence or not of Passavant's cushion in velopharyngeal closure, but the importance of it in the production of speech (Greene 1964: 59; Fritzell 1969: 10).

Many writers incorporated Passavant's cushion as an essential contribution to velopharyngeal closure in speech (Harrington 1944; Luchsinger and Arnold 1965: 449; Delattre 1969a, 1969b).

The absence of Passavant's cushion in certain individuals has been reported by writers like Calnan (1954), Greene (1964: 62) and Zemlin (1968: 309). Calnan (1953) came to the conclusion that the bulge produced in the posterior pharyngeal wall by the contraction of the superior constrictor muscle is located below the place of tight contact of the velum against the posterior pharyngeal wall. This fact would indicate that the bulging is, therefore, irrelevant in velo-pharyngeal closure. His finding has been confirmed by other researchers (Greene 1960: 62; Zemlin 1968: 309). In an investigation of 80 subjects, Hagerty et al. (1958) found the Passavant's cushion in only 9 individuals, and in 6 cases, the velopharyngeal closure occurred above it. Hagerty and Hill (1960) investigated 50 normal speakers and 50 cleft palate speakers pronouncing [a] and [s], and measured the anterior displacement of the posterior pharyngeal wall. They concluded that the contribution of this displacement in velopharyngeal closure during speech is insignificant because of the very small extension of the displacement in both normal and cleft palate speakers. Fritzell (1969: 10) is of the same opinion.

In spite of these findings, Passavant's cushion has been said to be more important in helping cleft palate speakers than in helping normal speakers (van Riper and Irwin 1958: 91; Kaplan 1960: 208; Zemlin 1968: 309). The most common opinion nowadays is that Passavant's cushion is not vital in speech, its presence in individuals is not consistent, and that it is more useful in pathological cases than in normal individuals. The pathological cases referred to above are cases of too short a palate or of a deep pharynx, when Passavant's cushion could help in diminishing the extent of the velic movement in the velopharyngeal closure or in cases of cleft palate speakers.

Chapter 3 : The Velopharyngeal Mechanism

3.1. The Velum

The most important part of the velopharyngeal mechanism is the soft palate or velum. It has many synonyms in the literature, such as velum palati, velum pendulum palati, septum palati, valvula palati, claustrum of the palati, etc. Kaplan (1960: 182) notes:

> "Velum is often synonymous with the soft palate, although it is more generally considered to be the lower portion of the soft palate that hangs down like an incomplete curtain".

Pike (1943: 85, 123) uses the term 'velar' for reference to the lower part of the soft palate, seen from the mouth, and 'velic' for reference to the upper surface of the velum that does not touch the tongue in velar stops. In the British phonetic literature, the term 'velar' refers to an oral place of articulation and the term 'velic' refers to the activity of the velum in general.

The velum is a muscular structure extending from the end of the palatine bone backwards, until it reaches the posterior pharyngeal wall horizontally (see Figs. 2, 6). It isolates the mouth and the pharynx cavities from the nasopharynx. It makes up the back part of the roof of the mouth, and the floor of the nasopharynx. The velum has a slightly concave undersurface, even when the velum is raised.

The velum can be envisaged as having three parts. The anterior part, attached to the hard palate, has few muscular fibres and functions as a hinge. The second part is the middle of the soft palate. This is a very muscular part. Zemlin (1968: 297) says that the bulk of the soft palate is made up of the levator palatini muscle. The posterior and third part of the velum has only the uvular muscle and the pendent uvula.

The velum is sustained and controlled during its movements by several muscles with a complex anatomy (see Part II, Chapter 2, Section 2.1.). The velum is anteriorly attached to the hard palate by the palatal aponeurosis. It is superiorly attached to the bone of the skull by the levator and tensor palatini muscles. It is laterally attached to the lateral pharyngeal walls of the nasopharynx, where the levator and tensor palatini muscles pass through, before they are inserted into the soft palate. The velum is attached latero-posteriorly by the horizontal fibres of the superior constrictor muscle. It is inferiorly attached to the tongue by the palatoglossus muscle and to the lower frontal part of the pharynx and to the larynx by the palatopharyngeus muscle. The palatoglossus and palatopharyngeus muscles make up the lateral posterior walls of the mouth and the faucal pillars (see Part II, Chapter 1, Section 1.5.). Finally, the velum hangs down free posteriorly, creating when lowered, the velo-pharyngeal port (see Fig. 2).

Bloomer (1953: 232), Fritzell (1969: 18) and Karabinos (1973: 18) state that the removal of the uvula has no apparent effect upon speech. However, this seems dubious, given the (presumably necessary) participation of the uvula in segments such as the uvular trill (Zemlin 1968: 300). The three authors cited above studied English speakers, and it is not common to find uvular sounds in English.

The velopharyngeal mechanism is controlled by the action of the velum. The function of the velum is not yet fully understood. Van Riper and Irwin (1958: 388) observe:

> "There is probably no basic mechanism in the entire speech process that has attracted more speculation and resulted in more controversy than the velopharyngeal mechanism".

The dispute is caused principally by lack of investigation of the velopharyngeal mechanism and by the difficulty of investigating what actually happens in this hidden area of the vocal tract during speech. Fritzell (1969: 12), for instance, says that 'it is difficult to visualize the anatomy of the palatal muscles by reading and studying illustrations alone'. As mentioned earlier, anatomical variation in this area can be considerable (Fritzell 1969: 12). Van Riper and Irwin (1958: 388-389) agree with Fritzell and say that the velopharyngeal mechanism may function differently for different activities such as speaking, swallowing and breathing, and that there are noticeable differences among individuals in speech.

Apart from its role as a passive articulator, the function of the velum in speech is to control the nasal and the oral ports setting up different degrees of oral and nasal coupling in relation to the pharyngeal cavity. One most important linguistic function of the velum is thus to control the oral/nasal feature in speech.

It is commonly found in phonetic textbooks (see, for instance, Brosnahan and Malmberg 1970) that the velopharyngeal mechanism is controlled by five muscles: two depressors (palatoglossus and palatopharyngeus), two elevators (levator and uvular) and one elevator-tensor (tensor). Although this classification must be slightly modified after the discussion above (see Part II, Chapter 2), we can say that the velopharyngeal mechanism shows three activities: elevation, lowering and tensing. These aspects of the velic activity will be discussed in the next sections.

3.2. <u>The Raising of the Velum</u>

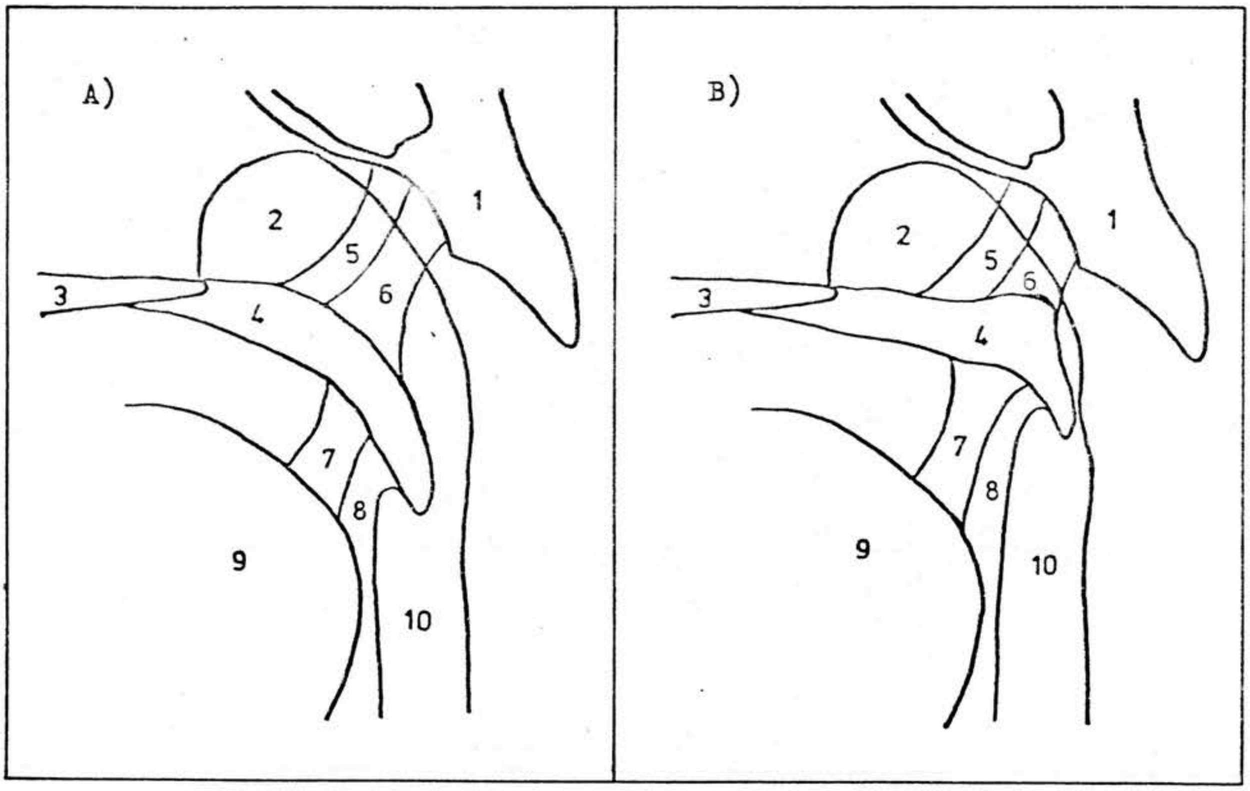
The mechanism which raises the velum is principally the action of the levator palatini muscle, which can be assisted by other muscles such as the palatopharyngeus and the superior constrictor (Dickson and Dickson 1972: 373, 379). The elevation of the soft palate is performed in order to close the velopharyngeal port or to constrict the opening (see Fig. 11).

The velopharyngeal closure may be performed by a sphincteric movement similar to the horizontal and vertical contraction of the lips or by a valve-like system with the velum functioning similarly to a small hinged trap-door (see Part II, Chapter 2, Section 2.2.).

To make a closure, the velum is typically compressed at the back against the posterior pharyngeal wall. The part of the soft palate which touches the pharynx is the middle third of the velum and the uvula is left practically free. The velic movements up and down do not follow a displacement in a vertical plane. During speech, the velum moves following an axis in a diagonal line related to the anatomical location of the fibres of the levator and palatoglossus muscles.

The configuration of the soft palate when lowered is similar to a banana in shape (see Fig. 11), but when it is raised to the maximum extension, the velum assumes a foot-like configuration turned downwards, with the corresponding part of the heel higher than the horizontal front part, and compressed against the posterior pharyngeal wall (see Fig. 11).

When the velum elevates, there is often a concomitant movement of the lateral pharyngeal walls medially. This movement during speech has been observed by several researchers (Hilton 1836; Wardill and Whillis 1936; Strong 1943; Harrington 1944; Bloomer 1953; Bosma 1953; Calnan 1955; Kaplan 1960; Zemlin 1968; Fritzell 1969; Dickson and Dickson 1972; Zagzebski 1975). This lateral movement has been denied by other researchers such as Björk and Nylén (1964). The medial movement of the pharyngeal walls during velopharyngeal closure has been attributed to one or to a group of muscles from the following



1. Sphenoid bone
2. Nasopharynx
3. Hard palate
4. Velum
5. Tensor palatini
6. Levator palatini
7. Palatoglossus
8. Palatopharyngeus
9. Tongue
10. Oropharynx

Fig. 11 Schematic diagrams showing how the velum moves in opening and closing the nasal port.

A): the velum is very lowered as for the articulation of a nasal. The nasal port is wide open and the oral port is narrowed;

B): the nasal port is almost completely closed and the oral port is wide open. The velum moves in a diagonal axis, following grossly the direction of the fibers of the Levator and Palatoglossus muscles. The action of the Levator on the velum makes it assume a foot-like shape with the heel blocking the nasal port.

list: superior constrictor, levator, palatopharyngeus, salpingopharyngeus. Dickson and Dickson raised the following hypothesis based on a study with dissections:

> "The angle and area of the velar insertion of the levator muscle led us to speculate that the levator, unassisted by any other muscle, may well be capable of moving the velum into the upward and backward position typical of velopharyngeal closure. The relative positions of the levator and the torus tubarius in the lateral pharyngeal wall led to the hypothesis that in velopharyngeal closure for speech, the levator muscle is responsible for both velar and lateral pharyngeal wall movement, a hypothesis consistent with the medial and posterior displacement of the torus tubarius in speech" (Dickson and Dickson 1972: 379).

According to Harrington (1944) and Bloomer (1953), the displacement of the lateral pharyngeal walls is directly proportional to the velic movements. Podvinec points out:

> "The larynx is lifted automatically, whenever the palate goes up. It remains in that position as long as the palate is kept in the position of closure" (Podvinec 1952: 454).

3.3. <u>The Lowering of the Velum</u>

The soft palate is not lowered by the force of gravity alone (Fritzell 1969: 48). The relaxation of the palatal elevator muscles is not enough for the velum to assume a lowered position. The velum can only be pulled down when the elevator muscles are relaxed and the depressor muscles are contracted.

The palatoglossus muscle (see Part II, Chapter 2) is the most important muscle in the mechanism lowering the soft palate (see Fig. 11). The constriction of the palatoglossus muscle can lower the velum only when the palatal elevator muscles are slightly relaxed. When the soft palate is kept in a fixed position by the action of the palatal elevator muscles, the constriction of the palatoglossus muscle will lift the back of the tongue (van Riper and Irwin 1958: 379; Kaplan 1960: 281; Zemlin 1968: 300; Fritzell 1969: 15, 56, 74). The co-ordination between relaxation of the levator muscle and contraction of the palatoglossus muscle has been observed by Fritzell in an EMG investigation. He says:

> "Lowering of the velum does not usually start until the levator activity has ceased completely or come to a standstill at a certain level, although the palatoglossus may show a great deal of activity long before that moment. This indicates that the levator is the stronger of the two and the more influential muscle as far as palatal movements are concerned" (Fritzell 1969: 67).

The principal function of the lowering of the velum in speech is to produce nasal consonants and nasalized segments. According to Calnan (1955), the velum, when not moving down to produce a nasal sound, does not move during speech, but is kept still (see also Greene 1964: 61). This point of view will be disputed later in the dissertation (see Part III, Chapter 1).

There is evidence from experiments showing that the velum is tensed and slightly lowered in preparation for speech, a few milliseconds before speech starts (Calnan 1955: 16; Moll and Shriner 1967; Fritzell 1969).

Delattre suggested a two-fold division of the movement of lowering the velum, one typical of nasal consonants and the other typical of nasalized vowels, with remarkable differences between the two categories. He writes:

> "For nasal vowels the velum is always lowered in the form of an arch, palallel to the curve of the tongue; for the (nasal) murmurs the velum usually maintains its square-angle shape and separates itself from the pharyngeal

surface - more exactly from Passavant's bulge - in a horizontal accordeon-like motion" (Delattre 1969a: 98-99).

More information about the velic movements will be given later (see Part III, Chapter 5).

3.4. The Timing of the Velic Movements

The movements of the velum in speech are fast and they are very well controlled. In normal speakers, the velic movements are fast enough to keep nasality under control when required.

The correlation between velic movements and the time necessary to produce them has been studied by Björk (1961: 399). He found that the velum closes the nasal port more slowly than it opens it. The time necessary to open the nasal port completely was found to be approximately 130 msec, and the time necessary to close the nasal port was approximately 160 msec. Moll and Shriner (1967) pointed out that the extent of velic movements is reduced when the speed of speech increases. Lübker (1968: 14-15) estimated the correlation coefficient between EMG activity of the levator muscle and velic elevation, and found a very high correlation (from .79 to .83); but the correlation coefficient between tongue height and velic elevation was much lower (from .55 to .61).

Björk (1961) found that the lingual movements are faster than the velic movements in speech, in the following proportion in an arbitrary scale: tongue movements = 100 - 200 - 300; and velic movements = 100 - 130 - 160. In a preliminary report of a special EMG investigation, Lübker et al. (1972: 233-234) found that the levator muscle activity ceases or is markedly reduced at about 100 - 250 msec before the audio signal onset for nasal consonants in nonsense words of the type VCNV and VNCV. The palatoglossus muscle activity was found to overlap the EMG activity of the levator most of the time, to have a short duration of activity, and to cease at about 100 msec before the audio signal onset for the nasal consonant. In meaningful (Swedish) words of the same type, the levator muscle activity revealed a shorter period of relaxation for the nasal, resuming its activity at the offset of that consonant, instead of resuming its activity well into the following vowel, as in the nonsense words.

Fritzell (1969: 58-76) investigated the latency between velic movements and EMG activity of the levator and palatoglossus muscles. He found that the EMG activity of these muscles precedes the corresponding articulatory gestures. He writes:

> "Determinations of onset of levator activity, velar (sic) movement and sound production were made and the time delays measured. A mean latency from onset of levator activity to onset of velar (sic) movement of 40 ± 60 msec was found. The mean latency from onset of levator activity to onset of sound was 334 ± 336 msec. When the total group of speech samples was divided into subgroups, it was found that sentences starting with a nasal sound [m] had a shorter EMG-speech latency than the rest. Sentences which initiated a series of speech samples, characterized by the situation where the subject was waiting for a signal to start, showed a longer EMG-speech latency" (Fritzell 1969: 75).

He also studied the EMG activity of the levator muscle compared with the EMG activity of the palatoglossus muscle as a function of the time of their action in speech, and the time of their EMG activity compared with the time of the velic movements pulling down the velum and raising it. He found that the palatoglossus needs more time to pull down the velum than the levator to raise the velum. He reports:

> "The mean delay from the midpoint of the palatoglossus envelope rise to the midpoint of velar descent was 88 ± 32

> msec. The mean delay from the midpoint of levator envelope rise to the elevation of the velum was 42 $\pm$ 37 msec" (Fritzell 1969: 75).

An example of Fritzell's measurements is given in Fig. 12. Fritzell's findings are of the same order as those reported by Iwashita (1965), Lübker (1967, 1968) and MacNeilage (1972: 19).

Faaborg-Andersen (1957) reported a latency between EMG laryngeal activity and sound ranging from 18 to 990 msec, with an average of 350-550 msec. Fritzell compared this data with the latency between EMG velic activity and sound and suggested that 'this might indicate that the laryngeal EMG-speech latency is longer than the palatal' (Fritzell 1969: 67).

In an extensive aerodynamic investigation of Russian articulations, Kozhevnikov and Chistovich (1967: 134) found that the velum was lowered for an average of 40 - 50 msec longer than the duration of the oral articulation of bilabial and alveolar nasals in intervocalic positions. When the nasals were preceded by oral consonants, the lowering of the velum lagged by an average of 27 - 33 msec. The rising of the velum for bilabial and alveolar stops following nasals, was delayed by an average of 50 msec. From these and other similar findings, they conclude:

> "From this data, it can be concluded that the minimum interval of time between two opposing movements of one and the same organ cannot be less than 55 - 70 msec. However, the interval between two closures can be considerably less than this value (10 - 20 msec), since in this case, the concern is with movements of different organs" (Kozhevnikov and Chistovich 1967: 135).

Warren (1976: 128) made the following observation about the timing between presence of nasal airflow and articulatory segments:

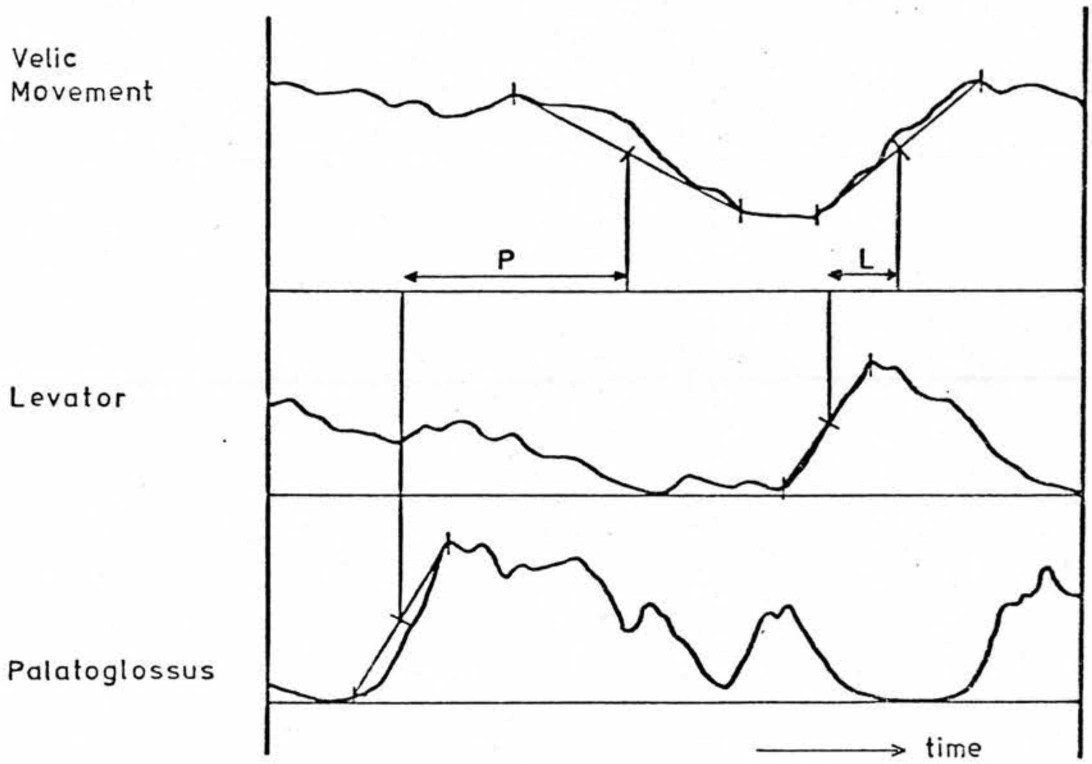


Fig. 12 Velic movement plotted against EMG tracings of Levator and Palatoglossus envelopes to illustrate how the movements of the velum follow the EMG activity pattern of the Levator, and to show how quickly the velum responds mechanically to the Levator (L) activity in comparison with a much longer latency when the Palatoglossus (P) lowers the velum.

(after Fritzell, 1969: 62)

"The velopharyngeal orifice opens well in advance and (in the sentence 'Are you home, Papa?) began as far back as the voiceless [h] in preparation for the nasal [m] . For example, the duration of the [m] segment is 120 msec compared to an opening interval of 284 msec prior to the initiation of the sound. The orifice, therefore, was open 404 msec, or nearly 3.5 times longer than the actual [m] segment ".

Pneumotachographic investigations carried out by the author did not reveal such a long overlapping velic activity in Brazilian Portuguese. In this language, velic activity coincides more precisely with the linguistic necessity for nasality or orality, as one can see in Fig. 29 (see also Part VI, Chapter 4). The most frequent cases of overlapping velic activity were found during the closure of the velum. Benguerel et al. (1977a, 1977b) found a different pattern for French.

PART III : THE CHARACTERIZATION OF NASALITY

Chapter 1 : Nasality and Speech Pathology

Speech therapists have been investigating the nature and characteristics of nasality for a long time, because excessive nasality is a common speech defect frequently treated in speech therapy clinics. Their contribution is highly valuable, not only to understand nasality better as a special voice quality in individuals, but also to understand the process of producing nasality itself. In the present thesis frequent reference to work done by speech therapists will be found and this shows how relevant their contribution is to a better understanding of the process of nasality in speech.

Unfortunately, the contribution of the speech therapists has not influenced the traditional way of describing nasality in phonetics, at least in introductory textbooks. The traditional linguistic phonetic approach is based particularly on a binary velic action opening or closing the nasal port. As we will consider later on, the articulatory bases of nasality are much more complex, and the mechanism producing nasality is not yet fully understood. For example, we will see that velic movements alone are not enough to characterize all aspects of nasality. Laver (1975: 179-180) comments on this saying that:

> "Segmental nasality is treated in most textbooks on general phonetics in a somewhat simplified fashion, and the simplifications are not always explicitly acknowledged. Of course, considerations of pedagogic expedience can quite reasonably inhibit writers of introductory texts from embarking on the often complicated explanations necessary to do justice to the detailed realities of nasality".

Some general aspects of nasality which are often considered by people who have a particular interest in speech pathology, will be discussed next.

According to Kaplan, nasality is a speech defect. He says:

> "Nasality is in a sense a disorder of articulation, since the vowels are given distinctive qualities by the position of the articulators as well as by the size and shape of the resonating chambers" (Kaplan 1960: 228).

Van Riper and Irwin (1958: 240) have a different opinion: 'nasality of itself, does not seem to be necessarily indicative of abnormality'. A slightly nasalized voice need not be regarded as a speech defect and certainly does not need to undergo speech therapy treatment. An accent may have nasality or denasality as a typical feature. But beyond a certain limit, too much nasal resonance or too little, when required, can be regarded as a speech defect (Kaplan 1960: 227; Greene 1964: 238).

What is meant by too much or too little nasal resonance is a very controversial point among writers, and most of them acknowledge the problem (van Riper and Irwin 1958: 249; Greene 1964: 238). There is a need for the establish~~e~~ment of a standard voice quality, accepted as neutral, with which other voices can be compared and assessed either as nasalized, denasalized or as normal voice. Another problem is that consistent and reliable assessment procedure must always be maintained when different voices are being judged in relation to the accepted normal quality. The task of establishing these categories gets more complicated when we incorporate evidence from different researches showing the masking effects upon nasality when speech disorders or different voice qualities occur together with nasality (van Riper and Irwin 1958: 249; Laver 1975).

In spite of all these difficulties, many attempts have been made to produce some sort of classification for different aspects of what is generally labelled nasality. Nasality can be referred to in other terms, such as 'to speak through the nose', 'nasal twang', 'nasal speech', 'nasal voice', 'nasal escape' (this latter term is usually reserved for the case when there is strong friction from the nose with a concomitant large amount of air flowing out). Terms for denasality include 'cold in the head voice', 'adenoidal voice', 'denasal voice', 'denasalized voice' (the last two terms are used to mean a lack of required nasality.) In more technical works, we find the following terms: rhinolalia, rhinophonia, and nasality. When one of these three terms is used in connection with the prefix hyper- (as in hypernasality), it means an excessive nasality. When these terms are used with the prefix hypo- (as in hyponasality), it means a lack of required nasality. Rhinolalia may be aperta or clausa, as Kaplan explains:

> "Rhinolalia aperta (hyperrhinolalia) may result from cleft palate, holes in the hard or soft palate, soft palate paralysis, faulty habits in the use of the soft palate, etc. The voice is hypernasal. Rhinolalia clausa (hypo-rhinolalia) has both anterior and posterior varieties. The anterior type is organic and involves different degrees of obstruction to the passage of air in the anterior part of the nose. There are anatomical deviations such as polyps. The voice may sound as though the person had a plugged nose or a head cold. The posterior type may be associated with organic lesions, such as adenoids or other growths in the nasopharyngeal region, or it may be functional. In the latter there may be permanent elevation of the soft palate during speech, along with contracted pharyngeal or tongue muscles" (Kaplan 1960: 229).

Rhinolalia may also be mixta, as Luchsinger explains:

> "There may also occur combinations of open and closed rhinolalia. If, for instance, open rhinolalia concomitant with paralysis of the palate is combined, due to chronic obstruction of the nose, with closed rhinolalia, rh. mixta organica anterior will arise. Paralysis of the palate concomitant with nasopharyngeal tumours will give rise to rh. mixta organica posterior. If a functional disturbance of the lifting mechanism of the velum coincides with stenosis of the anterior nasal passage, rh. mixta functionalis anterior will be the result. The same anomaly combined with nasopharyngeal tumours represent rh. mixta functionalis posterior" (Luchsinger 1968: 508-509).

More information about these terms can be found in Travis (1931), Moore (1957), Morley (1957), van Riper and Irwin (1958), Kaplan (1960), Greene (1964), Luchsinger and Arnold (1965), Zemlin (1968) and Heller et al. (1974).

Heller et al. (1974: 353) say that a common practice in evaluating nasality is to consider normal voice 0 in a scale going up to + 3, and down to - 3. The values + 3 and + 2 stand for severe and moderate hypernasality, and - 3 and - 2 for severe and moderate hyponasality, and + 1, 0, and - 1 for mild hypernasality, normal voice and mild hyponasality. The values + 1, 0 and - 1 constitute an acceptable voice quality in clinical terms.

Laver (1975) proposes two special velopharyngeal settings besides the normal or neutral voice quality. The first is a nasal setting and the second a denasal setting. Each setting has at least three degrees in a scale running from the neutral voice quality to slightly nasal or denasal, moderate nasal or denasal and severe (or extreme) nasal or denasal.

There are many causes for hypernasality or hyponasality. The common causes of hypernasality are: cleft palate, short palate, palatal paralysis, large nasal port, too large a pharynx, adenoidectomy, supranuclear paresis, nuclear lesions, peripheral neuritis, myasthenia gravis, deafness, emotional or neurotic disorder (van Riper and Irwin 1958: 246-249; Greene 1964: 244-261, 271; Zemlin 1968: 210). The common causes of denasality are: deflected septum, rhinitis, catarrhal conditions, polypoid growths in the nasal passages, adenoids when excessive, too long an uvula (Kaplan 1960: 229; Greene 1964: 271-275; Luchsinger 1968: 507). Hypernasality or denasality may emerge in the speech of a group of people, when members of the community start imitating someone in the community who speaks with a hypernasalized or hyponasalized voice quality. If the latter individual is an influential member of the community, this voice quality may become fashionable and be adopted by the community as a whole. Similarly, within a family, when the parents have a nasalized or denasalized voice quality, the children will probably be inclined to adopt those voice qualities too (van Riper and Irwin 1958: 248). Cases like this show that nasalization or denasalization may become a feature of the speech of a person without any anatomical or physiological trauma in the velopharyngeal mechanism. Nasalization (and more rarely denasalization) is used by some people as an individual feature, when they speak. We do not pay much attention to this aspect of speech, but it is surprising how many people we find speaking with a certain degree of nasalization. Their own voice does not generally stand out among other people's voice, and therefore, they are not usually considered cases for speech therapy.

Cleft palate speakers are of particular interest in the study of nasality. The cleft palate is a failure of the midline structures in the mouth to fuse completely. There is enough evidence to classify this as an hereditary factor. One can also have a cleft in the palate due to a traumatism acquired by means of an accident. The cleft may be located in a small or in a large area including the soft palate, the hard palate, the alveolar ridge and the upper lip. The person with cleft palate has problems with feeding, with social adjustment and with speech. The main speech problem is the necessary control of the airstream during phonation. Because of the permanent opening, air-pressure is always deficient and the result is usually a disruption of normal speech. Cleft palate speakers sometimes present a nasal grimace during phonation in an attempt to keep the airflow and air-pressure under control to a some extent. In a recent study of the innervation of the velopharyngeal muscles, it has been found that the levator palatini muscle is connected to the facial nerve, so that the typical grimace of cleft palate speakers can also be made during an attempt to control the levator muscle somehow to try and avoid excessive nasality. (Sedláčková et al. 1973: 438).

The cleft of the palate usually has a disrupting effect upon the articulatory process in general (Warren 1976: 130). The speech of a cleft palate speaker does not need to be necessarily hypernasalized, but it has a peculiar and typical quality that can be easily identified. The treatment involves a surgical correction of the abnormalities and speech training in a clinic (van Riper and Irwin 1958: 203-217; Greene 1964: 243; Zemlin 1968: 331). More information about the contribution of speech therapists to the study of nasality will be given in the next chapter.

Chapter 2 : Nasality and the Notion of a Cul-de-sac Resonator

2.1. The Participation of the Nasal Cavities in the Production of Nasality

It seems that the first writer to dispute the participation of the nasal cavities in the production of nasality was Eijkman (1926). In a letter to Sir Richard Paget, he says:

> "I entirely agree with you that what is commonly called 'nasal quality' has nothing to do with the passage through the nasal cavity or with resonance in that cavity. On the other hand I do not think that nasal quality has necessarily to do with passage through a narrow opening. I think it is rather a question of the addition of a high frequency resonance due to the formation of an additional resonating cavity of small size somewhere between the vocal chords and the nasal cavity. Experiments with models certainly seem to show that a nasal quality can be added by forming an additional constriction between the reed and a vowel sounding double resonance" (Eijkman 1926: 277-278).

Eijkman pointed out clearly that when dealing with nasality the only reliable criterion is the auditory one:

> "I cannot accept the view that an escape of air necessarily makes a sound nasalized. In my opinion the audible nasal resonance must be the criterion, and nothing else" (Eijkman 1926: 212).

I believe that he was the first to apply Helmholtz's notion of a stopped organ pipe resonator to explain the production of nasality by appeal to a side chamber in the mouth cavity in the case of the nasals (see Helmholtz 1862: 116-119). After saying that the supraglottal passages are formed by large cavities with narrow apertures, Eijkman observes that in the production of a bilabial nasal, to the nasal and combined pharyngeal and laryngeal cavities 'is added the mouth as a blind appendix with a small back entrance: it works like a stopped organ pipe' (Eijkman 1926: 218). Earlier when discussing the cause of nasalization, he notes that

> "Small cavities with small apertures are apt to produce twangy resonances, because they may be compared to stopped organ pipes, which produce only odd partials, owing to which a great many tones sound hollow and even twangy" (Eijkman 1926: 214).

Paget (1930) did a number of experiments with analogue models of the vocal tract to test nasality. He made, for instance, a model 'formed of a rubber tube (about 1 inch diameter and 5 inches long) attached to an organ reed and fitted with a cork tongue', and he concluded:

> "It was found that if, while the reed was sounding, the tube was suitably pinched, near the opening from the reed, an appreciable twang was added to the vowel-sound... This experiment indicates that a part, at least, of the so-called nasal quality of the pronunciation now in question, is probably due to a constriction of some part of the pharynx, so as to produce an additional resonator of high pitch, though the presence of nasal resonances seems also to be indicated" (Paget 1930: 96 - see also p. 211).

Another way of producing nasal quality in his models in the case of nasal consonants, without the use of a nasal cavity resonator, was found by piercing a very small orifice near the internal constriction in the tube prepared for the nasal consonant. In this sort of model, the constriction has very narrow passage. Paget comments:

> "The continuous hum - which is an important characteristic of all three sounds (bilabial, alveolar and velar nasals) - was produced by a leakage at the closure. The same effect can be produced in the human voice, but the articulatory change is certainly less defined than when these sounds are made as in normal speech" (Paget 1930: 215).

Finally, Paget (1930: 237) found that using a model of substantially larger dimensions than those of the human mouth, the addition of a nasal cavity was effective only when 'the resonance of the additional cavity was in unison with the reed frequency'.

2.2. The Notion of a Cul-de-sac Resonator and Nasality

Russell used the X-ray technique on a large scale to study the articulations of speech. The X-ray pictures showed very clearly the configuration of cavities in the vocal tract during speech, and he was particularly impressed by the configuration of the bottom of the pharynx and upper part of the larynx and the different positons assumed by the epiglottis in changing this area. Moreover, he knew the experiments by Paget producing a nasal quality by constriction near the reed of his analogue models. On the other hand, the X-rays showed that the lowering of the velum and the velopharyngeal closure did not control the production of nasality and orality consistently. So, Russell found it quite possible to explain certain nasal qualities by the configuration of the cavities immediately above the glottis, disregarding the velic action. It is interesting to notice that he made an explicit statement saying that he found oral sounds in speakers with the nasal port not completely closed, but in spite of the suggestion of formation of nasality in the lower pharynx and larynx, he did not report any case of a subject who produced 'nasal twang' with the velum closed and the epiglottis and lower pharynx in a special configuration.

It seems that he started the use of the expression 'cul-de-sac' to explain the production of nasality, although the concept comes right from Helmholtz and the people who used Helmholtz's ideas to explain speech production in terms of resonators. The quotation below suggests that Russell got his ideas about the cul-de-sac resonators from Paget, through one of his colleagues:

> "Where the tonal quality is distinctly nasal the cushion of the epiglottis is often seen almost to close upon the cartilages of Wrisberg. This may be due not only to the pull excercised by the aryteno-epiglottideus muscle but also to a contraction of the arymembraceus muscle, and to a downward tipping of the arytenoid cartilages which would throw their superior prongs forward. When this closure takes place, it will be seen that a sort of cul-de-sac might well be created between the vocal lips themselves and the superior narrowing of the opening. However, it must be said that this is not clearly visible from the top.
>
> Yet if a cul-de-sac is formed there might well result a nasality of quality analogous to that produced by Sir Richard Paget when he lays the open hand against the throat just above the Adam's apple and forcibly presses in. And that nasality, on a smaller scale, it is true, might well be expected if we compare it with the well-known result produced by vowels passing into the nose when we have a cold, or when we pinch the nostrils with the fingers and so create a cul-de-sac.
>
> Prof. T. Earl Pardoe, a brilliant former colleague of the author, was wont to illustrate these varying results and the theory above enunciated as to the effect of nasality as compared with nasal resonance, in these two types of voice quality by vowels, both of which were permitted free access to the nose" (Russell 1931: 240).

Russell suggested the term 'nasal twang' for the nasality produced in the interior of the larynx, and the term 'nasality' and 'nasal resonance' for a function of the nasal passages (Russell 1931: 164, 174, 213, 239-240 and 244).

It seems interesting to quote two other passages by Russell about the notion of a cul-de-sac resonator and the production of nasality:

> "The reader who is not a trained phonetician might also do well to remember that an opening into the nose does not

necessarily mean nasality of tone. Most men with resonant bass voices speak practically all their vowels with the nasal passage open. It is only when the tone is penned in, in some sort of a cul-de-sac, that it turns out to be what is called 'nasal' in quality. This penning in is regularly accomplished by the lips and tongue when we pronounce an M, N or NG; by growths and the swelling of the turbinates as in colds; by certain constrictions in nasal muscles utilized especially by those with cleft palates; by an excessive constriction in the pharynx for certain 'nasal twang' tones such as the one Sir Richard Paget cleverly imitates by laying the flat hand against the throat above the Adam's apple and pressing in forcibly; and finally (as shown by the author's laryngoperiskop) by a constriction between the cushion of the epiglottis, arytenoids, and false cords above the glottis" (Russell 1931: 18).

And,

"An excessive constriction produced by the epiglottis, by the interior larynx, or between the tongue and the walls of the pharynx, may cause the lower pharyngeal cavities to form such a cul-de-sac. There is then given off a tonal quality which the ear recognizes as being somewhat analogous to that produced by swollen turbinates" (Russell 1931: 42).

We must also point out the fact that Russell believed that nasality was not only produced by a special type of cavity, but also by the 'influence of soft surfaces' as 'physiological filters' damping not only 'the complex sound as a whole but especially the high-pitched metalic partials' (Russell 1931: 174).

West et al. (1937), cited by Laver (1975: 186-187), developed the concept of cul-de-sac resonator in the production of nasality and gave other alternatives regarding this process and the location of possible cul-de-sac resonators along the vocal tract. They explained the concept of cul-de-sac resonance as follows:

> "The timbre, or overtone structure, usually given the name 'nasality' is the result of resonance in a cul-de-sac (Russell 1931: 18) resonator, a chamber opening off from the passageway through which a sound is resonated and delivered to the outer air. If a medicine bottle were attached to the side of a saxophone, with the bottle opening tightly fitted to one of the lateral vents of the instrument, the bottle would serve as a cul-de-sac resonator. The saxophone would have a nasal quality not unlike that of a bagpipe, in which there is a system of cul-de-sac resonance. If a small hole were pierced in the bottom of the bottle, the nasal quality, though still present, will be somewhat reduced. If this hole is enlarged until it is greater than the lateral vent to which the bottle is attached, the nasality will disappear and the bottle cease to act as a cul-de-sac resonator.
>
> Wherever, along the tube from the larynx to the outer air, there is a side chamber whose only opening is into the main tube, there is a chamber capable of acting as a cul-de-sac resonator and of producing a quality of tone usually referred to as nasal; and wherever this side chamber has an accessory opening through it to the outer air, it may still function as a cul-de-sac resonator if the accessory opening is smaller than the aperture connecting the side chamber with the main tube" (West et al. 1937: 78).

See also West et al. (1937: 79, 80, 85 and 431) where more information about cul-de-sac resonators is given.

As one can see, their description closely coincides with Paget's results. It should be noted that West et al. use the term 'side chamber' as a synonym of cul-de-sac resonator. The new points put forward by them will be discussed later, but first, I would like to make few marginal comments.

The example of the saxophone with the attached bottle is not a good one because this particular instrument (without any bottle attached to it) is characterized by having a very strongly nasalized quality, principally when the low pitched notes are played. The nasal quality which is typical of bagpipes when the bellow is full of air tends to disappear as soon as the piper starts to produce different notes. It is an interesting area of research and discussion however, that different voice qualities, principally nasality, should be attributed to different musical instruments. Later in this chapter we will discuss the role of vocal tract analogues and the production of acceptable nasality, but we are not going to comment further on how different musical instruments are said to produce a timbre which we are ready to accept as being nasalized, such as the saxophone.

At this point, we can sum up the discussion about the production of nasality and the notion of cul-de-sac resonance so far, by saying that:

a) Nasality is the result of a cul-de-sac resonance.

b) A cul-de-sac resonator is a side chamber attached to the main tube and smaller than the main tube.

c) If the side chamber has an aperture to the outer air, this aperture must be smaller than the inlet of the side chamber.

d) A side chamber with an aperture to the outer air has its resonance decreased in intensity.

e) If the outlet of the side chamber is larger than its inlet, the side chamber does not produce nasal resonance.

2.3. Different Factors Producing Different Types of Nasality

The concept of cul-de-sac resonator or side chamber explains the function of the nasal cavities producing nasality when free from obstruction, when the nostrils are pinched up or even when a person has cold in the head and the mucous plug does not completely fill the nasal cavities, but leaves a small chamber at the back. It is also interesting to notice that when only one nostril is closed, the 'degree' of nasality decreases. With both nostrils open, the 'degree' of nasality is even smaller. Van Riper and Irwin (1958: 243) prefer to talk about different varieties of nasality instead of different degrees of nasality in connection with the discussion presented above. West et al. (1937: 80) suggests:

> "In view of the considerations as to the phonological nature of 'nasality', it would probably be much better to refer to this quality as 'cul-de-sac resonance' rather than 'nasal resonance'. Hence, we should say that the sounds M, N and NG are produced by buccal cul-de-sac resonance, and that the nasalized vowel is produced by a nasal cul-de-sac resonance".

West advanced a hypothesis that the tendency of some hypernasal speakers to flaring or pinching the nostrils during speech may be due to an attempt to reduce the amount of nasality by making the nasal port smaller or equal to the outlet of the nostrils. He says:

> "I suspect that if the cross-section of the nasopharyngeal port is equal to or less than that of the outlet through the nostrils, then our cul-de-sac (resonator of the nose) will again cease to function as such, but will function as a double-ended resonator or sound delivery tube, thus providing two outlets for the laryngeal tone, one through the mouth and one through the nose" (cited by van Riper and Irwin 1958: 243).

West et al. (cited by Laver 1975: 191) suggested other possible cul-de-sac resonators along the vocal tract besides the nasal cavities and the mouth, in the production of nasality. They say:

> "Frequently there comes to the speech clinic a person whose voice is distinctly 'nasal' in quality, but whose vowel sounds are made with the nasal port unmistakably shut tight. Where is the cul-de-sac responsible for his nasality? Many

> guesses have been made in answer to that question - a pouch formed back of the larynx at the mouth of the oesophagus, one formed between the epiglottis and the root of the tongue, two side pouches formed between the alveolar ridges and the cheeks. But wherever the cul-de-sac is in such a case - and it may be in any or all of these places - this 'nasal' quality usually disappears when the patient learns to phonate with relaxed throat and tongue. It may well be that the constriction of the muscles pulls apart surfaces of the larynx and pharynx, of the epiglottis and tongue, or of the cheek and alveolar ridges, that would otherwise be in contact, thus creating cavities in which this 'nasal' quality can be produced" (West et al. 1937: 79).

Kelly (1934), Williamson (1944) and Gray and Wise (1946) reported that some speakers with hypernasal speech present too narrow a mouth opening. They suggested that the hypernasal voice was caused by the narrowing of the mouth opening, transforming the mouth cavity into a cul-de-sac resonator.

Tarneaud (1941) also, working with speech pathology, adopts the notion of cul-de-sac as responsible for the production of the so-called 'nasal twang', without the participation of the nasopharynx or nasal passages. He believes that a cul-de-sac might appear in some part of the vocal tract due to an excessive tension of the muscles. According to him, the most common place to find a cul-de-sac, other than the nasal cavities, is in the mouth. His comments are as follows:

> "It is not a tone given by the rhinopharynx and the nasal fossae. In fact, the study of its production shows that the velic passage is shut with the velum against the posterior pharyngeal wall. That particular tone is wrongly considered to be nasalization, since its acoustic characteristics and its physiologic mode are quite different. It is produced by means of the stiffness and the fixation of the walls of the oropharyngeal resonator, accompanied by the formation of a

> cul-de-sac by one of the muscular elements of these walls being overconstricted, mainly the velopalatine arch. To those who know how to hear it, the tone is semiguttural and seminasalized, given the fact that nasalization corresponds to an almost complete closure of the velum" (Tarneaud 1941: 67 - the translation is mine: see Appendix 1, (c)).

It is interesting to quote, in passing, another passage from his book related to the problem of nasality:

> "This fact is well-known by singers; as a matter of fact, it has been noted for the first time by J. and M. Glover who pointed out that beyond a certain high note, variable according to individuals, it is impossible to nasalize a sound" (Tarneaud 1941: 69 - the translation is mine : see Appendix 1, (d)).

Hixon (1949 - quoted by McDonald and Baker 1951: 11) compared X-ray pictures from speakers with normal and nasalized voices and observed that the speakers with nasalized voices had a tendency for the oral cavity in front of the highest point of the tongue, to be much larger in size, than he found in normal speakers. He also found that speakers with nasalized voice tend to have higher positions of the tongue than normal speakers. McDonald and Baker (1951: 11) reported that, if a speaker saying [ã] has his tongue lowered with a clinical tongue depressor, the articulation becomes less nasalized.

Greene (1964: 67) states that a nasal twang can be produced by constriction of the faucal pillars. She says:

> "Nasality may in fact be achieved by elevation of the dorsum of the tongue and constriction of the pillars of the fauces even when velopharyngeal closure is complete. This takes place in the speech of some English people but is more conspicuous in American dialects when the cul-de-sac resonator imparts a nasal 'twang' to the voice" (Greene 1964: 67).

According to the foundations of a cul-de-sac resonator theory explained earlier, the constriction of the pillars will produce nasality only when there is a complete closure in the anterior part of the mouth cavity or when there is an aperture that is smaller than the constriction produced by the faucal pillars. The constriction of the oral port producing 'nasal twang', as we saw earlier, has been suggested by Eijkman and Paget in a different manner, applying only in the case of nasal consonants.

The notion of cul-de-sac has been consolidated in the literature by the works of Russell and West. After them, many authors have used this notion to explain nasality, some of them with some skepticism, and others adding new ideas to this notion.

Curry (1940: 98) explained the production of the 'nasal twang', that according to him is typical of the American pronunciation of New England, saying that it is produced by 'violent contraction of the larynx with an additional narrowing of the larynx aperture'.

Stein (1942: 171) explains the same 'nasal twang' saying that it 'is caused by a pharyngeal constriction'. He also points out that

> "Since not only the nose but also the pharynx is capable of producing 'nasality', of the voice, the classification of the disorders of nasal resonance could better be based on the acoustic than on the anatomical or physiological aspect" (Stein 1942: 172).

McDonald and Baker draw attention mainly to the configuration of the oral and nasal port, because

> "There is a critical point in the degree of closure of the nasopharynx. It is at this critical point that a characteristic balance or ratio is established between oral and nasal resonance. If this critical point is not reached, nasality will occur" (McDonald and Baker 1951: 11).

This quotation (also cited by van Riper and Irwin 1958: 246) shows how the importance of the oral:nasal ratio emerged from the investigation of the function of the apertures of the side chamber and the main tube within the theory of cul-de-sac resonance. Ever since, the oral:nasal ratio notion has been more often investigated and used than the simple location of possible cul-de-sac resonators in the production of nasality.

Berry and Eisenson (1956) stated that a nasal twang may be the result of a constriction in the pharynx, in the faucal pillars or tension anywhere in the supraglottal region (cited by Kaplan 1960: 215).

House (1957: 199), who used an electric vocal tract analogue to study nasal consonants, points out:

> "Theoretical considerations indicate that such anti-resonances (of nasality) in the spectrum are to be expected in situations where the acoustic path from glottis to output has side branches, or cul-de-sac portions as discussed by Russell (1931) and West et al. (1937), among others. Such side branches, of course, do not generally exist during the production of non-nasal vowel sounds. The frequency position of the anti-resonance depends upon the length of the side branch, being lower in frequency for the longer side branches".

Van Riper and Irwin (1958) reviewed the literature about nasality in general and particularly about the causes of it, and they concluded:

> "In addition to the explanation of an escape of sound from air blown through the nose, various other explanations have been suggested. Among these are: a small mouth opening, a high tongue position, a retracted tongue position, a cul-de-sac in the pharynx or oral region, and even an unusual mode of vibration in the larynx" (van Riper and Irwin 1958: 207).

In connection with the discussion of the coupling of cavities in the production of nasality, van Riper and Irwin observe:

> "We feel that the most reasonable conclusion is that excessive nasality may be produced in either or both ways - by having too wide an opening into the nasopharynx or too small an opening into the mouth" (van Riper and Irwin 1958: 242).

Van Riper and Irwin pointed out that an air tight closure of the velum is not essential for the production of oral sounds. Thus, during the production of some oral sounds, the velum may allow some air to flow into the nasal cavities without producing audible nasality. Because of facts like the above, van Riper and Irwin attribute a 'functional closure' to the nasal port based on the audible perception of nasality, rather than in the presence or absence of nasal airflow (see Part III, Chapter 5).

Kaplan (1960: 176-180) explains the theory of resonant cavities and uses the term cul-de-sac to explain the 'nasal' quality of segments:

> "In nasal sounds the fauces leading to the mouth is narrowed, and the mouth acts as the cul-de-sac. The nose becomes the cul-de-sac in sounds chiefly involving oral resonance" (Kaplan 1960: 179).

However, he does not mention other possible cul-de-sac resonators in the vocal tract besides the two cavities in the quotation above.

Rose (1962) follows Russell (1931) and West et al. (1937) and also retains the classification of nasal quality traditional among singing teachers:

> "It (nasal resonance) should be understood as a concept synonymous with head tone and not confused with nasality or nasal twang - an unpleasant quality achieved, not by

> opening the entrance to the nasal cavities, but by penning the sound in a cul-de-sac" (Rose 1962: 216).

He accepts a cul-de-sac formation in the nose (when it is blocked) or in the mouth (when the cavity has no outlet to the outer air), but he is suspicious about other possibilities:

> "It is not well known, however, that a similar cul-de-sac may be formed in the lower pharyngeal cavities by constriction produced by the epiglottis, by the interior larynx, or between the tongue and the walls of the pharynx when the throat is closed. There is then given off a tonal quality which the ear recognizes as being somewhat analogous to that produced by swollen turbinates" (Rose 1962: 216 - see also Russell 1931: 18).

Van den Berg (1962), cited in Laver (1975: 190), acknowledges the possibility of nasal quality being produced in some part of the vocal tract other than the nasal cavities. He says:

> "Nasality is immediately recognized by the human ear, but the acoustical correlate is difficult to describe exactly... This might seem to be important for the phonetician and not for the phoniatrist, but this would be a mistake... Nasal qualities, at least qualities which are interpreted as being nasal, may arise without participation of the nose, by too large damping factors at other places of the vocal tract, primarily in the vicinity of the larynx as found by the author by experiments with Fant's static electrical analogue of the vocal cavities" (van den Berg 1962: 117).

In this quotation, the emphasis is put on the fact that nasality is always associated with 'large damping'. As we saw earlier, Russell believed that nasality was produced not only by the side chamber, but also by the action of soft structures of the vocal tract damping the sound. This large damping, as an acoustic cue for nasality, is very noticeable in the occurrence of nasality, as a quasi-permanent feature of the voice quality of some speakers.

Greene (1964: 239-243), when discussing nasality, notes that 'modern research largely confirms Paget's experimental findings' and accepts the principle of cul-de-sac resonance to explain the production of nasality. She observes that more important than the nasal escape of air in the production of excessive nasality is the tension in the vocal tract and the general configuration of the supraglottal cavities including the laryngeal cavity. She also draws attention to the possibility of producing nasality in other parts of the vocal tract besides the nasal cavities:

> "Nasality (is considered) mainly in relation to the nose and palato-pharyngeal competence, but it should not be forgotten that nasality may also be imparted to the voice by muscular constriction in the laryngeal cavity and the relative positions assumed by the ventricular folds, aryepiglottic folds and epiglottis, also elevation of the larynx by the suprahyoid muscles. This is why relaxation of muscular tension in voice therapy is a constant theme" (Greene 1964: 240).

She also refers to different nasal qualities produced by different variations in the oral and nasal ports, obstruction in the nose, tension, excessive air pressure, close-mouthed articulation and the relationship between coupled cavities.

Lindqvist (1964) in a study of speech using an inverse filtering technique, points out the fact that the nasal port often does not have a complete closure during the production of normal 'non-nasal' vowels. This is acoustically relevant because 'this could introduce an error in the resulting waveform' in an unexpected way. The following is another interesting observation made by Lindqvist:

> "Another condition which was not considered in the design

> is the coupling to the subglottal system. Under normal conditions this coupling is supposed to be very small. In pathological cases, however, where the subject has an incomplete closure of the glottis, the coupling to the subglottal air may cause additional pole-zero pairs which may not be apparently different from those caused by nasalization at least when only the frequency range below 1,500 cps is considered. The main difference is the time variation within one glottal cycle which is the case only for a subglottal coupling" (Lindqvist 1964: 3).

Lindqvist states, however, that the effect of

> "This additional pole-zero pair upon the resulting waveform is generally not very significant, since the residue amplitude of this subglottal pole is anyway small" (Lindqvist 1964: 3).

Van den Berg (1962) investigated the acoustical characteristics of the subglottal cavities and found resonances similar to the resonances that characterize nasality. He says:

> "It appears that the subglottal air system behaves almost like a tube open at one side (corresponding with the alveoles in the lungs) with resonances, or subglottal formants at about 300, 900, 1,500 cps, etc. The bandwidths of these resonances are about equal to those at comparable resonant frequencies of the vocal cavities" (van den Berg 1962: 83).

Zemlin (1968: 210) adopts the view that nasality and its variations are controlled by the amount of coupling of oropharyngeal and nasal cavities, in other words, by the oral:nasal ratio. He refers to research carried out by Fletcher (1947) showing that hypernasal speakers have a different mode of vibration of the vocal folds compared with normal speakers. He mentions several authors that found similar results, such as Paget (1930), Russell and Tuttle (1930), Russell

(1931), Travis, Bender and Buchanan (1934), Warren (1936) and Curry (1940). He also reports that

> "Earlier authors had also suggested that nasality may have its seat, at least in part, in the larynx. Curry (1910), for example, postulated that nasality could be caused by insufficient velo-pharyngeal closure, by pharyngeal constriction, or by excessive tension in the larynx, or by a combination of all of these" (Zemlin 1968: 210).

2.4. How Nasality is Produced by Analogue Models of the Vocal Tract

It is interesting to have a look at the construction of analogue models of the vocal tract in order to see how the builders incorporated the complexity of cavities of the human vocal tract and particularly the nasal cavity in their models.

Analogue models of the vocal tract are devices capable of producing synthetic speech that can be checked up by the human ear. They are generally of three types: mathematical, electrical, or mechanical (or articulatory) analogue models.

Mechanical analogues imitating the articulatory function of the vocal tract were used in earlier experiments. The first speech synthesizers were built in this way. In von Kempelen (1791), the nasal feature was produced by two openings (called 'nostrils') near the reed, i.e., the source of the sound (see also Flanagan 1965: 167). In Kratzenstein's vowel sounding pipes (1782), the possibility of producing nasality was not investigated (Paget 1930: 12-13). The experiments by Miller using organ pipes were concerned chiefly with the acoustic properties of speech and did not investigate nasality. Stumpf, using organ pipes, also investigated nasal consonants (Paget 1930: 27) but I could not find more information about him. Helmholtz (1862), as we said earlier, conducted some experiments and came to the conclusion that a stopped organ pipe (acting as a side chamber) gives a nasalized quality to the sound, and this idea is the underlying principle of the notion of cul-de-sac put forward by Russell (1931). More evidence for Helmholtz's discovery was achieved by Paget (1930) making resonator analogues of the vocal tract. Paget also found that nasality could be produced by piercing a hole near the reed (see the beginning of this chapter). A recent mechanical analogue of the vocal tract was made by Riesz (1937), as reported by Flanagan (1965: 169). His model is much more similar to the vocal tract than the previous experiments, in that nasality is produced by controlling a switch (velum) that allows the air to go first into a special channel (nose) and then leave by means of an independent opening called the nostril. The velic coupling is variable in size, and the nasal passage and nostrils have a constant cross-sectional area. The maximum cross-sectional area of the velic coupling is equal to the cross-sectional area of the nasal passage.

Mathematical analogue models can be tested by means of electrical analogues, so that we have the mathematical analysis of speech and an artificial reproduction which can be checked by ear. Pioneer work in this direction was done by Chiba and Kajiyama (1941). In making their model, the authors realized the 'complexity of cavities' in the human vocal tract and decided to remove this difficulty by converting the complex human vocal tract into a 'cavity of simpler shape which nevertheless should have a value acoustically equivalent to that of the actual vocal cavity' (Chiba and Kajiyama 1958: 112). The result of the conversion produced a series of variable cavities (about 11 in number) representing the lips, ~~t~~eeth, mouth, pharynx, larynx and glottis. They did not incorporate the nasal cavities at all. However, it is interesting to notice that they found a resonance with the frequency of 3,200 cps being common to all five vowels studied, and this frequency was attributed to a resonance in the larynx cavity. They comment:

> "If the larynx cavity be considered as a closed pipe of uniform thickness, the pipe should be 2.8 cm in length in order that the resonant frequency may be 3,200. The length of the larynx cavity varies considerably with different individuals, but in our experiment it was estimated from X-ray photographs at 2 - 2.7 cm in the case of male adults. The end correction is fairly large, since at the top of the larynx, the cavity is open only posteriorly and closed both anteriorly and at its sides; therefore an effective length of 2.8 cm is possible" (Chiba and Kajiyama 1958: 147).

This quotation is interesting because it gives us an estimated acoustical value of the resonance of the laryngeal cavity, believed by many people to produce resonances similar to nasality. But this investigation at least showed a resonance of 3,200 cps that is absolutely insignificant as far as the acoustics of nasality are concerned. Chiba and Kajiyama (1958: 94-99) also investigated the effect of the 'softness' (flaccidity) of the vocal tract walls upon the vowel quality. They found Russell's point of view too extreme and after many experiments, they concluded:

> "Summing up, the flaccidity of the walls of the vocal organs produce no great effect upon the vowel quality: it makes a little change in the frequency characteristics of the vocal organs with the result that the quality of tone is but slightly affected. It is the shape and size of the vocal cavity that play an important part in determining the vowel quality" (Chiba and Kajiyama 1958: 99).

See also van den Berg (1960: 372-374).

The production of nasality due to large damping caused by the electrical characteristics of the synthesizers, is not a rare problem in the design and construction of speaking machines. Van den Berg (1960: 114) comments:

> "The damping of the resonances due to the resistances in the tract cannot easily be calculated. It is interesting to note that Dunn's analogue at first produced vowels which sounded nasal, while his analogue had no 'nose'. The nasal qualities disappeared after careful cleaning of all contacts, i.e., by reducing the damping in the vocal cavities".

Stevens, Kasowski and Fant (1953), following Chiba and Kajiyama (1958), and Dunn (1950), made an electrical analogue of the vocal tract. The vocal tract was treated as a series of cylindrical sections of variable size and the electrical device as a 'cascade of electronic lumped sections', each of them being able to produce the resonance typical of the section in question. They did not incorporate the nasal cavities in this model. About the restrictions in the conversion of the vocal tract proper into the coupled analogue cavities, they state:

> "The shape of the vocal tract may deviate markedly from that of a straight acoustic tube. There is always a curvature in the tube, and in addition irregular ducts or branches are often coupled to the sides of the main tube. For example, the [l] is produced by splitting or diverting to one side the path of the sound from the pharynx to the lips. An additional cavity is, of course, utilized in the production of nasal vowels and consonants, but even for non-nasal sounds there may be slight coupling to the nasal cavity. At frequencies for which the dimensions of these nonuniformities in the vocal tract are comparable to the wavelength, the approximation of plane wave propagation is likely to be in error by a considerable margin. For most of the non-nasalized sounds in normal speech, however, the

error is probably quite small" (Stevens et al. 1953: 741).

House and Stevens (1956) incorporated a nasal tract analogue to a vocal tract analogue as described by Stevens et al. (1953), and they investigated the nasalized vowels. The nasal cavity was regarded in the analogue as a single tube with a series of sections, some of them variable, some fixed. The nasal tube was connected 8 cm from the glottis (the length of the whole vocal tract analogue has 17 cm). Near the coupling there were three variable sections in the nasal tube representing the nasopharynx. Variations in the cross-sectional area of the coupling sections produced different degrees of 'velopharyngeal closure'. When the cross-sectional area was zero, the velum was closed. They investigated the effect of constricting the oral port when the velum is lowered and found this to be not relevant acoustically:

> "The nasal analog is coupled to the VTA (vocal tract analog) at a point 8 cm from the glottis. The action of the velar (sic) strictures in the analog is in some respects unlike velar activity in the human talkers. In the analog the dimensions of the vocal tract do not change when the velum is lowered, i.e., when the cross-sectional area of the variable sections of the nose is increased. The effects of moderate changes in the dimensions of the VTA in the vicinity of the velum have been investigated informally, however, and have been found to produce a negligible change in the acoustic spectra of synthetic nasalized vowels" (House and Stevens 1956: 220-221)

House (1957) improved the nasal tract analogue referred to above and studied the production of the nasals. He mentions the possibilities of existing cul-de-sac portions from the glottis to the output as side chambers and he cites Russell (1931) and West et al. (1937). However, he does not make any special comment, except to say that we do not actually know the origin of all antiresonances that we find in the real speech spectrograms (House 1957: 199).

Fujimura (1961, 1962 and 1963) in his analysis-by-synthesis of the nasals, treated the entire vocal tract as a compound of three cavities: pharynx, oral and nasal cavities, and assumed that all three were acoustically joined together only at their ends at the velum. In his model, the nasal cavity or nasal tract is formed by the nasal passages and the nasopharynx. He did not suggest any other possibility of producing nasality.

Hecker (1961, 1962) constructed a dynamic analogue of the nasal cavities (DANA) with geometrical dimensions similar to the nasal tract analogue used by House (1957). He studied the synthetic production of the nasal consonants. Hecker assumed a total nasal tract length of 12.5 cm with 9 sections. The two first sections (3 cm unit) represented the nasopharynx and were electronically variable, with a cross-sectional area varying from 0.05 to 5 cm^2. He found the 'desired zero minimum area' of coupling not feasible in practice. Section 3 had a variable cross-sectional area varying in the following scale: 2.0, 4.0, 6.0, 8.0 and 10.0 cm^2, permitting studies relating the size of the corresponding region of the nasal cavities to the acoustic output. Sections 4 to 7 represented the region of relatively constant area (2.6 cm^2) and section 8 again offered manual control (0.4, 0.8, 1.2, 1.6 and 2.0 cm^2). Section 9 representing the anterior nasal port had a cross-sectional area of 0.42 cm^2 (Hecker 1962: 180).

Flanagan (1965) treated nasality as the effect of a side chamber cavity generating antiresonances (zeros). He pointed out that the zeros (like the poles) are uniformly distributed in frequency. Flanagan also observes that side branches occur in 'nasal consonants, nasalized vowels and perhaps liquids such as [l] ' (Flanagan 1965: 181). The integration of poles and zeros of nasality results in somewhat broader and more highly damped resonances than those of the vowels. Flanagan continues saying that

> "Additional loss is contributed by the nasal tract which over a part of its length is partitioned longitudinally. Its inner surface is convoluted, and the cavity exhibits a relatively large ratio of surface area to cross-sectional area. Viscous and heat conduction losses are therefore commensurately larger" (Flanagan 1965: 68).

Mainly because of this last remark, the analogue models of the vocal tract represent very crude and simple approximations of the real facts involved in the production of nasality by the human vocal tract. Fant (1960), in his physiological mapping of vocal tract dimensions in order to build his mathematical and electrical analogue, used only the pharynx, the mouth and the nasal cavities, besides the 'characteristics of the source'. But he mentions the possibility of coupling other cavities to the main system such as, for instance, subglottal cavities (trachea, lungs) (Fant 1960: 60). Fant points out the difficulty in dealing with small side branch cavities (shunting paths) in the theoretical calculations:

> "A few other systematic factors influencing the calculations should be mentioned. The sinus piriformis constituting the bottom of the pharynx cavity on both sides of the larynx tube has been neglected since its shunting effect on the sound transmission from the glottis was not very easily taken into account in the numerical calculations" (Fant 1960: 102-105).

However, Fant conducted some interesting experiments to investigate the effect of these cavities on the final output of sound. He used a 6.5 cm^2 cross-sectional area tube 17 cm long. The first two centimetres in this tube were reduced to 2 cm^2 cross-sectional area, representing a constriction at the bottom of the pharynx-larynx cavity. As a result, an increase in the density of the poles in the frequency region of 3,500 up to 5,000 cps was found, caused by the introduction of one additional pole and the readjustment of the poles in that region. And Fant concluded:

> "There is thus some sense in affiliating F-4 with the larynx tube resonance as has been proposed by Sovijärvi (1938a, 1938b) and Chiba and Kajiyama (1958)" (Fant 1960: 105).

In the next experiment, Fant introduced a new shunting cavity to the modified tube, representing the sinus piriformis. The effect was to produce a zero at about 5,000 cps with the consequent abrupt cut-off of sound energy in that region. The introduction of false vocal cords in the model produced only a very small additional low-pass filtering effect. Fant sums up the results:

> "The effect of the terminating cavity systems at the larynx is thus essentially to cause a pronounced low pass filtering effect with a cutoff at approximatelly 5,000 cps. As pointed out by van den Berg (1955) an effect of this general type can be thought of as part of the source characteristics. The theoretical effect of omitting the sinus piriformis from the calculations, as will be done in all other calculations reported in this work, is thus to cause somewhat too high estimates of those formants frequencies that are primarily dependent on the pharynx cavity. The effect is probably greatest in back vowels. In addition the suppression of the spectrum region above 5,000 cps is less pronounced" (Fant 1960: 105).

2. 5. The Didactic Phonetic Approach

Let us now consider what is found in textbooks on Phonetics regarding the notion of cul-de-sac resonances in the production of nasality, or the participation of some parts of the vocal tract other than the nasal cavities in the production of nasality. Our review is spread in time, starting from Bell (1867) up to O'Connor (1973).

Bell (1867) considers the vocal tract as a windpipe made up of different and interconnected cavities. He explains the production of nasality in what we can call the 'traditional approach', that is, nasality is produced by the lowering of the velum and the speech airstream flowing into the nasal cavity. However, in passing, we should note his view that the action of the velum (or soft palate, or 'uvula' in his terminology) closing the nasal cavity is not done backwards against the pharyngeal wall, but upwards, so that when the soft palate is raised, the posterior nares are closed. He illustrates this 'action of the soft palate closing the nasal passage' in a diagram (Bell 1867: 13), and he describes it as follows:

> "The passage of the nostrils is governed by the soft palate which acts the part of a valve. When there is no nasal emission, the upper surface of the soft palate presses against the inner end of the nostrils" (Bell 1867: 47).

Sweet (1906), after Bell, also used the traditional approach to explain the production of nasality. But he explained the movements of the velum in a different way:

> "The lower pendulous extrem~~e~~ity of the soft palate, the uvula, can be pressed backwards or forwards" (Sweet 1906: 8).

He explained the nasal twang as an imperfect closure of the velum and observed that a wider opening is needed to produce a nasalized vowel. He says:

> "If the nose passage is kept only slightly open, we get the nasal twang of many American and English speakers... In

languages which distinguish between nasal and un-nasal vowels the nose opening of the former is necessarily more marked than in a mere nasal twang" (Sweet 1906: 20-21).

Various degrees of nasality are recognized by Sweet (1877) and he relates them to various degrees of opening of the nasal port. An interesting passage from Sweet, related to our discussion of cul-de-sac resonators, is the following:

> "The pure nasal vowels, which are common in many South German dialects, must be carefully distinguished from the French nasals, in which there is guttural compression as well as nasality... (Footnote: The exact formation of the French nasals has long been a disputed question. The guttural element I believe to be some kind of lateral cheek - and, perhaps, pharynx - compression: it is somewhat vaguely described by Mr. Bell as consisting in a 'semi-consonant contraction of the guttural passage'... I now doubt the necessity of any guttural compression in the formation of the French nasals: this deep tone may be due simply to the greater lowering of the uvula than in South German and American nasality)" (Sweet 1877: 7-8 - see also page 211).

Sweet (1906: 8, 12) makes reference to changes in the position of the epiglottis during speech, and even to a special effect caused to speech sounds by a possible narrowing of the bronchial passages. He does not attribute any type of nasal quality to these articulations, however.

The next author to be considered is Pike (1943). He states in his first chapter on 'marginal sounds':

> "Sounds produced or modified by larynx, pharynx, false vocal cords, and epiglottis are often considered abnormal in spite of the physiological normality of their processes. These sounds are paid but scant attention in description of the vocal apparatus. They seem little understood, since they are difficult to produce and, furthermore, have but slight

place in phonetic systems" (Pike 1943: 8).

Pike (1943: 8), in a note, gives a long list of works, including Russell, where the upper parts of the vocal tract have been reported to have a function during speech. He also observes that the use of a system of air chambers with a variety of closures and partial strictures still remains unclassified in the normal description of phonetics. On the other hand, Pike draws attention to the fact that the 'feeling of completeness' as aimed at by Doke who decided to mark everything, leaving 'nothing to deduction' in his analysis, is very illusory. Pike continues in his criticism of Doke's analysis, by saying:

> "In the [n] which he (Doke) mentions, what is the position of the back part of the tongue? of the roof of the tongue? of the epiglottis, the faucal pillars, pharyngeal wall? of the cheeks, the jaw, and entrance to the oesophagus? how long was the sound held, and with what pitch and intensity? what type of transitional sounds did it have before and after it?" (Pike 1943: 21).

This quotation is interesting because it shows the procedure of filtering the features of the sounds we usually make in the everyday work of phonetic analysis, to produce in the end only the most important and obvious characteristics of the sounds. Linguistically, there is no need to go further and even in a narrow phonetic analysis, we make very gross characterizations of the sounds. The aim of a linguistic analysis is not to exhaust the acoustical output of real speech, but to isolate only the principal features that are relevant for the linguistic system. In the case of the production of nasality, for example, if the linguistic system can satisfactorily explain nasality by adding a nasal cavity to the oral tract, it does not need to seek other possible articulations to produce nasality. This point of view is most of the time tacitly accepted or presupposed in many books on phonetics. Although this approach can be very convenient for pedagogical purposes and for a general description of the production of sounds, however, the phoneticians should never forget, for example, that nasality can be produced in other parts of the vocal tract besides the nasal cavities. This point, perhaps, may complicate the linguistic analysis, but it may be, sometimes, the only true explanation for certain qualities we recognize as being nasalized. For this reason, in the study of nasality, the phonetician must not forget to incorporate the role played by the minor cavities of the vocal tract in his model of speech production.

Pike (1943: 85-87) considers the vocal tract to be a compound of five cavities: the oral, nasal, pharyngeal, pulmonic and oesophageal (including the stomach) cavities. The cavities form 'air-chambers' which can be active or passive. He says:

> "The air chambers in specific use for a particular sound, the one which contains the air stream, is the 'active' chamber. All other chambers are 'passive'. In the examples ... ([a] and [n]), the oesophageal chamber was always passive. The nasal chamber is passive for all oral sounds; the oral and nasal chambers are passive for glottal stop. During [p] the oral-pharyngeal-pulmonic chamber is active, and so on" (Pike 1943: 86-87).

Pike's theory about air-chambers is strange. It represents a description of the configuration of the vocal tract rather than a specific effort to show the effect and real participation of these air-chambers in producing specific acoustic features of the sounds. In practice, however, Pike will assign a special function only to the pharynx, mouth and nasal cavities, as we found in common descriptions of the production of the sounds in phonetic textbooks. He does not say what the exact function of the pulmonic, oesophageal and laryngeal cavities is in modulating the speech sounds. Pike explains what a side chamber is, in the following way:

> "When part of an active air chamber does not have the air stream passing directly through it, but only by it, that part becomes a side chamber. This is seen almost exclusively during the production of front nasals such as [m] or [n]" (Pike 1943: 87).

So, strictly speaking, in the production of nasalized vowels, for instance, following Pike, there is no formation of a side chamber to produce nasality. Pike calls the opening of a side chamber a 'valvate stricture' or 'valvate articulator' (Pike 1943: 129-130). He considers the opening into the oesophagus as a special type of valvate stricture and calls it 'subvalvate'. Pike considers the stricture of the faucal pillars independently from other articulators and holds it to be responsible for the quality of voice called by him 'faucalization' (Pike 1943: 134). Pike employes a large and detailed classification of different types of strictures attributing to each of them a special articulatory function. He also says that this classification leads to different acoustic effects, but he does not elaborate this point (Pike 1943: 129-148). So, in conclusion, although Pike mentions several minor cavities in the vocal tract, he does not attribute the production of nasality to any of them, but only to the nasal cavity.

Heffner (1950), cited by Laver (1975: 179), also uses a traditional approach to explain the production of nasality. However, he observes that this explanation must be understood with restrictions:

> "The contraction of the pillars of the fauces is a feature of the production of nasal vowels. However, a generally accepted genetic explanation of true nasality, or nasal twang, is not yet available. In any event it is evident

that the mere passage of all or of part of the breath stream through nasal cavities does not of necessity produce what we call nasality" (Heffner 1950: 31-32).

What he means by 'contraction of the pillars of the fauces' in the passage above is quite ambiguous, because the pillars can be constricted either by lowering the velum or by a constriction of the palatopharyngeus muscle without lowering the velum. However, the second part of the quotation shows clearly that he recognizes the difficulty in the location of the production of nasality in the vocal tract, as well as recognizing what one might call nasal quality auditorily.

Heffner is of the opinion that 'the epiglottis may have some influence upon the quality of speech sounds', but he does not specify what kind of effect it should be (Heffner 1950: 27-28).

Heffner, following Paget, explains that acoustically a nasalized vowel presents two typical resonances, one ranging from 2,169 up to 3,906 cps and the other from 400 up to 450 cps. The former is attributed to resonance in the nose, and the later in the nasopharynx, and he cites Paget and Eijkman. Heffner then continues:

> "The passing of a part of the breath stream through the nose as a result of an inert, or laxly lowered velum may cause the low component frequencies characteristic of the nasal cavities to be selectively passed and hence to be more clearly audible than when the velum is raised and these partials are not thus favored, but the quality difference produced by this lax lowering of the velum is not a change to nasality, but a 'richening' or 'mellowing' of the vowel sound. Nasality is produced only by a more vigorous lowering of the velum plus the constriction of the posterior pillars of the fauces. There are degrees of this vigor, to be sure, and the French nasal vowels are much more vigorously nasalized than are the nasal vowels of Danish, German or

Portuguese dialects" (Heffner 1950: 113).

Heffner cites Paget (1930) and Russell (1931) many times in his book, but he does not mention explicitly the concept of cul-de-sac, although he clearly states that we do not know yet the exact mechanism which produces what we can accept as nasality. It is interesting to note how he interpreted Eijkman's suggestion of production of nasality behind the lowered velum by attributing it to the nasopharynx which together with the oropharynx couples to the nasal cavities (Heffner 1950: 90). In this passage, the nasopharynx is not regarded as part of the 'nasal cavities', but as part of the 'pharynx'. This is another divergent point among phoneticians. Some of them use the term 'nasal cavities' or 'nasal cavity' to mean the passage from the nostrils to the velopharyngeal opening, others use it to mean only the double channel of the nose excluding the nasopharynx, still others incorporate the nasopharynx into the nasal cavities only when the velum is raised and the nasal port is shut; when the velum is lowered, the nasopharynx forms the upper part of the pharyngeal tube. The nasal port in the last case is the posterior nares. Heffner, for instance, follows the third group of phoneticians. We must also point out that the function of the nasopharynx is often used in a very confused way in the phonetic literature (see Part II, Chapter 1, Section 1.2.).

In Rosetti (1962) we find some comments about nasality that are not usually present in phonetic textbooks. Besides the traditional explanation of the process of nasalization, he points out that nasalization sometimes does not coincide precisely with the expected oral articulations and produces an 'abnormal nasality'. He states that it is natural for the velum to assume different positions during the production of different oral and nasalized vowels, and that the elevation of the velum in this case, is formed in a scale from open vowels to close vowels (Rosetti 1962: 74). Rosetti notices that in the production of [a] it is common to have a small opening in the nasal port. He also says that one can find occasionally nasal resonances produced without air escaping through the nose, but set up by the propagation of the vibrations from the mouth into the nasal cavity through the soft structures of the soft palate (Rosetti 1962: 75). He also refers to the fact that nasality varies among individuals and languages.

Denes and Pinson (1973: 63) mention that at the lower end of the pharynx, the shape of the vocal tract does not only change during swallowing, but also during the production of speech. However, they do not say in what way this change influences the sounds. They also point out that our knowledge about the acoustics of the sound come more from synthesis with simplified models of the vocal tract than from a real understanding of what is actually produced by the different articulations in the human vocal tract (Denes and Pinson 1973: 83).

Abercrombie (1967: 29-31, 48, 63-64) considers only the traditional explanation for the production of nasality in his book: if the nasal port is open, there is nasality; if not, the sound is oral.

In Brosnahan and Malmberg (1970), in spite of its being an introductory book to Phonetics, we find wider reference to technical works and results, markedly in the field of acoustics, than is usually found in textbooks. About nasality, they conclude that 'there is no simple feature of the spectrum which can be consistently associated with nasalization' (Brosnahan and Malmberg 1970: 68). They attribute special resonating roles to the trachea, epiglottis and Morgagni's ventricles in the production of speech. They say:

> "The cavity formed by the bronchi and the tube of the trachea probably acts as a resonator to vocal sounds of low frequency" (Brosnahan and Malmberg 1970: 31).

The epiglottis can modify the 'timbre of the laryngeal tone' (Brosnahan and Malmberg 1970: 33). Talking about Morgagni's ventricles they say that 'these probably have a certain resonatory effect on sound produced in the larynx' (Brosnahan and Malmberg 1970: 34). However, they do not specify what exact acoustical value these cavities have upon the final output of the sound produced in speech, neither do they specify the exact auditory quality these cavities give to the overall quality of the voice. As a maater of fact, they are more inclined to consider the function of these small cavities as irrelevant to the final output. The following passage illustrates this point:

> "There are other minor cavities also, which may be included or not, and which in some cases can be varied in shape: one between the teeth and the lips, another under the tip of the tongue, the laryngeal sinus, and so on. Not all these cavities, of course, need play a role in any one case of sound production" (Brosnahan and Malmberg 1970: 60).

Everywhere else in their book, the process of nasality is treated in a traditional way (Brosnahan and Malmberg 1970: 39, 67-68, 110-113).

One of the most recent textbooks on Phonetics is by O'Connor (1973). In it he states that the epiglottis has no function at all in speech production (O'Connor 1973: 31-32), and that, in the production of nasality, it is important to allow some part of the airflow to be shunted into the nasal cavity, although it is not necessary to allow it to exit from the nostrils:

> "In other words, for nasalized sounds the important thing is that the air should pass into the nasal cavity, but not

necessarily out of it through the nostrils" (O'Connor 1973: 33).

It is surprising that in a book published by Catford (1977), where the articulatory possibilities of man ~~is~~ are explored in great detail, one cannot find any reference to the possibility of the production of nasality other than by the lowering of the velum, following the very traditional approach to this matter.

In addition to the above list of phonetic textbooks, we would like to comment upon a recent discussion of nasality by Laver (1975: 164-203). Laver is one of the few phoneticians not directly interested in speech therapy to discuss the notion of cul-de-sac in order to explain the production of nasality in a more complete way. As we will see later this notion is of special interest in his work, since it is not used to make a diagnosis of speech defects, but to explain in a better way the phenomena of nasality as a quasi-permanent feature of individual voice quality. In his work we find an extensive review of the literature about nasality and a comprehensive description of the anatomy and physiology of the velopharyngeal mechanism, and the present dissertation takes his work as a point of departure. Though Laver uses the traditional approach of conventional phonetic description of nasality to explain the nasality that characterizes special segments in languages, he does not believe that this traditional approach is the unique articulatory explanation for the quality of voice we can recognize as nasalized. Even the traditional approach is not accepted unconditionally, following the conventional description of nasality, that is, by the simple rising and lowering of the velum. The oral:nasal ratio is an essential feature in the production of nasality in his point of view.

Laver reviews several works on speech pathology dealing with nasality and discusses the notion of cul-de-sac presented by them. He accepts the theory of side chamber resonance, as the true explanation for what happens when the nasal tract is incorporated to the oral tract in the production of the nasals and nasalized vowels. He also accepts, as possible, the formation of other side chambers in the vocal tract different from the nasal cavities or the mouth (in the case of nasal consonants), and the action of these side chambers can be to produce a quality recognizable as nasality.

Laver is aware of the lack of research in this area and points out that the only effect of a side chamber in the production of speech that is satisfactorily well known, is the coupling of the nasal cavity to the oral tract, producing the nasal resonance in the strict sense of 'nasal'. In addition to that, he notices that 'the discussion of side chamber resonance other than that involved in resonance of the nasal cavity is speculative at present' (Laver 1975: 194-195). He therefore concludes:

> "Not enough is yet known, in phonetics at least, about the sources of side chamber resonance in the pharynx, larynx and faucal pillars, to be able to differentiate accurately between the different types on an auditory basis, and until this is possible, it seems premature to develop an over-delicate descriptive terminology" (Laver 1975: 195).

About the location of possible side chambers other than the nasal cavities, Laver suggests that in addition to the other possibilities found in the literature, it is possible to form one between the two sets of faucal pillars, and in the case of velar or uvular nasals, the cavity of the mouth in front of the closure can become an extra active chamber as well, when it is put in resonance by vibrations travelling through the tongue. He says:

> "Also in velar and in uvular nasals, the surface of the tongue forward of the closure with the soft palate, if touched with a finger tip, can be felt vibrating with any but the very weakest degree of voicing. The surface of the tongue can therefore excite the resonances of the front of the mouth, and the oral cavity forms a resonant chamber in the formation of these two nasal stops" (Laver 1975: 189).

2.6. Conclusion

Finally, I must add to the discussion so far, a very short remark giving my point of view on this matter. The side branches suggested by many writers, besides the nasal cavities and the mouth, are very small, producing an acoustical effect only on a very high range of frequency, and hence cannot be said to be primarily responsible for nasality, but they may contribute secondarily to this quality. The notion of cul-de-sac resonator in the production of nasality, when applied to chambers other than the nasal cavities in the case of the nasalized sounds, and the mouth in the case of the nasal consonants, is very speculative, and nobody has yet succeeded in bringing forward irrefutable evidence to prove satisfactorily that nasality is being produced primarily by these special side chambers. Many suggestions have been put forward, but very little conclusive evidence has been achieved in the past fifty years of research.

Chapter 3 : Airflow and Production of Nasality

The results of experiments about airflow through the nasal cavities during the production of oral and nasal sounds constitute perhaps the most controversial aspect of the study of nasality. The problem is highly complex, and its complexity is due principally to the fact that the airflow characteristics need to be analysed in relation to the mechanical functioning of the velum controlling the nasal port and in relation to the perceptual characterization of nasality. Three main issues have been the object of controversy in the literature: one is the fact that the velopharyngeal port may not be completely closed for all oral sounds, which then show a small amount of nasal airflow during their production; the second issue is the fact that it is possible to have nasality without any air flowing into the nasal cavity; and the third issue is the relationship between the relative amount of airflow and different degrees of nasality.

The airflow can be easily measured instrumentally by means of flowmeters and audible nasality can be assessed by the ear, but the movements of the velum and the nasal port offer considerable difficulties in the investigation of their action in speech (see Part IV). Thus, the statements about the relationship between velic movements, airflow and nasality found in the literature are based for the most part on assumptions rather than on real evidence from experiments.

We will now proceed to discuss these three issues. First, let us consider the relationship between velopharyngeal opening, escape of air and non-nasal sounds. The escape of air and the area of the velopharyngeal opening is assumed to be in a direct relationship, that is, if there is an escape of air through the nose, it implies a velopharyngeal opening; if there is no escape of air from the nose, the nasal port is completely sealed. This assumption is not completely true, because it is possible to put the air which is inside the nasopharynx in motion and consequently have it flowing out from the nose. This is done by movements of the velum during velopharyngeal closure or by internal displacement of the lateral pharyngeal walls, for example, when opening the aperture of the auditory tube. In both cases, of course, the amount of air that can be released from the nostrils, will be very small. Lübker and Moll conducted an investigation of the nasal airflow together with cinefluorographic observations and made the following remark:

> "Thus it is possible that, with a closed velopharyngeal port, nasal flow of air may exist in either direction (ingressive or egressive) because of movements of the closed velum which create changes in nasal cavity size. The possibility that such small burst of nasal flow are caused by velar (sic) movement is substantiated when air volume is computed. For example, (in one case), a total volume of approximately .0042 liters of air is expired from the nose as speech is initiated. A very small change in nasal cavity dimensions could account for such an expiration" (Lübker and Moll 1965: 268).

Smith (1972) found that there were very small amounts of ingressive and egressive nasal airflow during stops, pronounced with the nasal port closed.

After a long discussion of how tight and complete the velopharyngeal closure must be in speech and after an extensive review of the literature about this issue, van Riper and Irwin concluded that the following statement is untrue or at least exagerated:

> "The escape of all or any part of the air-sound stream through the nose will of necessity result in a quality that we regard as nasal" (van Riper and Irwin 1958: 392).

In support of this particular passage, they cite the works by Kantner and West (1941), Mc Donald and Baker (1951) and Heffner (1949). Greene says:

> "Elevation of the palate is also of vital importance to the production of good speech. The prevention of nasal

escape of air is of great importance in the articulation of consonants. Slight escape of air down the nose (i.e. 'nasal escape', or 'nasal emission') does not necessarily mean vowel nasality, but the ability to compress air in the oral cavity is very necessary for the articulation of fricatives and plosives. Massengill and Bryson (1967) carried out a cinefluorographic study of the velopharyngeal function as related to perceived nasality of vowels in normal subjects, judged by a speech class of students. Although nasality increased with increasing size of palatopharyngeal aperture as expected, some subjects were judged nasal despite complete closure and others even with as much as an 8 mm gap were judged as having normal tone" (Greene 1964: 58).

It has been reported by some writers that men with bass resonant voice have the tendency to have a permanently open nasal port without producing audible nasality (Harrington 1944; Berry and Eisenson 1956; Greene 1964: 24; Laver 1975: 185). Warren (1964: 161) found that with a nasal opening of 10 mm^2, a stop instead of a nasal was perceived. Other similar findings have been shown by Kaltenborn (1948) and Björk (1961).

Rousselot with a large experience of recording the airflow from the nose and the airflow from the mouth separately with the kymograph, observes:

"Nasal vibrations are found even in the traces of either vowels or consonants that one believed to be absolutely oral. This fact can be explained by vibratory movements transmitted through the tissues. But it can be due also to the passage of a small amount of air through the nose, which is compatible with the purity of the auditory impression. This is, in fact, what happens" (Rousselot 1924: 526-527 - the translation is mine; see Appendix 1 (e)).

See also Rousselot (1924: 268, 287, 526-531, 572).

The possibility of producing an oral vowel with concurrent airflow from the nose, has been reported by Nusbaum et al. (1935), as quoted by van Riper and Irwin (1958: 243). The possibility of producing nasality without air flowing out from the nose has been reported by van Riper and Irwin (1958: 242-243, 392) and Laver (1975). The latter makes the following observation about this point:

> "The presence of nasal airflow is by no means an obligatory factor in the production of an auditory quality listeners are ready to accept as nasality. A posterior nasal blockage (...)(cold in the head) does not necessarily prevent the resonance of the nasal cavity; the cavity may well be acoustically excited by sound waves travelling either through the nasal plug or the tissue of the velum itself, just as earlier it was suggested that the oral cavity could be made to resonate quite audibly by whispering while maintaining a uvular closure and velic opening. If the tongue can demonstrably allow the transmission of the low amplitude sound waves produced in whispering, then it doesn't seem unreasonable to suggest that the velum may allow the higher amplitude, voiced waves to be transmitted into the nasal cavity" (Laver 1975: 197).

A special case to be considered now is the production of nasal resonances when the speaker has a nasal blockage caused by the presence of excessive nasal mucus, when he gets a bad cold in the head. One way of producing nasal resonance when the nasal tract is blocked as described above, has already been mentioned in the last quotation by Laver (1975: 197). A similar example might be when the blockage leaves a cavity behind it, mainly in the nasopharynx, which can resonate when connected to the rest of the vocal tract, thus producing nasality. Contrary to a certain popular belief, a person with a cold in the head tends to have more commonly a special kind of nasality rather than some sort of denasality. Laver comments:

> "The quality of some (not all) voices of speakers with a

> head cold is not 'denasality' in the strict sense of a complete absence of nasality, but rather a special, very highly damped kind of nasality"(Laver 1975: 197-198).

Another special case happens when the nostrils are pinched close and the airflow is not allowed to leave the nose. In this case, the nasal cavities can resonate and the effect is perceived as a special sort of nasal quality given to the nasal sounds in the final output. When the nostrils are blocked, the nasal cavity functions as a typical side branch resonator as the mouth does in the production of the nasals (see Part V). The two types of blockage of the nasal passages give different acoustical characteristics to speech because of the different volume of the side chamber left behind the blockage. From the perceptual point of view, the two types of resonance produce two different types of nasality which are easily perceived by the ear.

The assumption that different degrees of nasality are directly related to different levels of nasal airflow volume or nasal sound pressure variations as shown by many devices which are used in the investigation of nasality (see Part IV) is commonly accepted. However, Rousselot observed no relationship between amount of airflow and a proportional increase in the severity of nasality on his kymographic traces. He writes:

> "There are dialects where an abnormal and very abundant flow of air out of the nose, does not produce very noticeable nasalization" (Rousselot 1924: 269 - the translation is mine; see Appendix 1 (f)).

Benson (1951) did not find any relationship between the amount of airflow and relative degrees of perceived nasality either (see van Riper and Irwin 1958: 242). Karabinos (1973: 10, 36) has a different opinion and states that variations in the amount of airflow recorded by an Aerometer reflect the different positions assumed by the velum in order to produce the required auditory effect for linguistic nasality. Karabinos' suggestion is questionable, however, since airflow characteristics are not constant. The problem is much more complex (Warren 1967: 154-155; Laver 1975: 182). It must be remembered that sound is basically independent of airflow, and that nasality, as a product of a resonance in the nasal tract, is characterized by the rules of resonance production, rather than by the simple passage of airflow through the cavities. So, as we have already pointed out, it is a very complex matter to know exactly what the participation of the airflow is in the production of nasality.

Airflow characteristics in speech are often assumed to have what Warren (1964: 53) has called a 'fictitious average steady motion'. This assumption reflects a dangerous simplification that may jeopardize the validity of some experimental conclusions. This point will become clearer after the discussion that follows.

First of all, the speech airflow is not laminar or uniform, but turbulent and the airflow characteristics are constantly changing throughout the speech process. Warren comments:

> "Flow is not always laminar, however, because of the branching, irregular shape of the respiratory tract. Eddying occurs at bifurcations and when the surface is rough or constrictive" (Warren 1976: 108).

The aerodynamics of speech must not be confined to the study of airflow volume as a function of time, but must also include the investigation of different types of air movements, air pressure, flow rate, density of air, viscosity, direction of the flow and especially airflow resistance. In addition, the aerodynamic aspects of speech must be correlated with other processes such as oral articulation, phonation, etc. Airflow characteristics are different in speech and in breathing (Warren 1976: 108-109). The control of the aerodynamics of speech by the brain to produce the correct physical conditions for the production of speech is not well understood. The airflow changes continuously, due to the constant articulatory changes that take place in the vocal tract for the production of different speech sounds. So far, we have very limited information about how airflow variations are readjusted during the production of a series of sounds, each of them requiring special aerodynamic control.

A very important aerodynamic factor is the flow resistance. In the nasal aerodynamic process of speech, two types of flow resistance are of special importance. The first is the nasal orifice size, whose resistance controls the shunting of the airflow into the nasal tract. The second is the airway resistance caused by the shape of the nasal chambers, which obstructs the airflow. Warren carried out experiments in this area and found that

> "... once the (velopharyngeal) opening is larger than 20 mm^2, other factors, such as a nasal airway resistance, influence intraoral pressure more than palatal valving. Under normal conditions, intraoral pressure for nasal sounds will depend upon respiratory volume as well as nasal cavity resistance" (Warren 1976: 129).

He also found that

> "The nasal pathway presents a constant resistance of approximately 1.0 cm H_2O/L/sec to 4.0 cm H_2O/L/sec in normal, unobstructed individuals" (Warren 1976: 127).

Warren also investigated the relationship between airflow and relative degrees of velopharyngeal opening with a special technique (see Part IV, Chapter 1), and concluded:

> "Contrary to reports of other investigators, the present study indicates that all ranges of velopharyngeal incompetency cannot be reliably estimated from measurements of nasal emission of air. The correlation between the two decreases in strength as sphincter inadequacy increases in magnitude" (Warren 1967: 154).

Laver is of the opinion that we should give less importance to the presence or absence of airflow in the production of nasality, and more attention to the auditory aspects of it. He says:

> "Thus, clearly, airflow through the nasal cavity is not itself a necessary or sufficient condition for the production of audible nasality. (Which, incidentally makes the nasal airflow trace on an electrokymogram a less than reliable indicator of nasality). Nasality is essentially a condition of resonance (...), and the nasal cavity can resonate without the passage of air through it; one has only to think of the possibility of very marked nasality where the nostrils are held tightly closed, for example" (Laver 1975: 182).

Finally, it must be said that, although nasality is not necessarily dependent on the release of airflow, nevertheless, nasality is at least partly related to air escape. The recording of a small level of airflow does not necessarily mean that a small degree of nasality is being produced during that period of time. However, the recording of a high level of nasal airflow is certainly an indication that some sort of nasal resonance has been added to the sound during the period of time related to the presence of airflow, since a large amount of airflow cannot be put in motion and escape from the nose unless the nasal port is wide open, coupling the nasal cavities to the oral tract. This indication of nasality when a large amount of nasal airflow is recorded, however, is a gross indication, and does not allow us to conclude anything about the degree of nasality, since as we know from experiments by Warren (1964; 1976) and other researchers, discussed earlier in this section, the amount of nasal airflow is neither correlated with velic opening area, nor with different degrees of nasality.

As we reported earlier, nasality can be produced by resonating a cul-de-sac chamber different from the nasal cavities. This manner of producing nasality may be used to characterize a nasalized voice quality which is present during large stretches of speech (i.e., during stretches of speech larger than the syllable, for example). In addition, in a language where nasality has a phonological function, the segmental nasality must be produced under strict control, and must fit the short duration of individual segments. It seems, therefore, highly improbable that this latter type of nasality can be produced and controlled in speech by means of a cul-de-sac resonator different from the nasal cavities. Although there is not a necessary relationship between nasality and airflow, nevertheless, the segmental nasality which has a phonological function can be indicated by the presence of a certain amount of nasal airflow picked up by flowmeters, but the nasality which characterizes an individual voice quality, which can be produced without the participation of the nasal cavities, is less likely to be indicated by the presence or not of nasal airflow (see Part IV, Chapter 1, Section 1.3.).

Chapter 4 : The Oral:Nasal Ratio

Nasality is more than the lowering of the velum or the opening of the nasal port. It is also a matter of special resonance, and therefore, it is primarily an auditory feature. Speech therapists have found it a problem to decide on different degrees of nasality when making a diagnosis of normal and hypernasalized voices, for instance. The first approaches were based on subjective judgements, using, for example, the technique invented by Gutzmann to pronounce the vowels [i] and [a] alternatively, and then with the nose pinched closed. If there is a change in the quality, the vowel is said to be nasalized and the speaker a nasal speaker (See Part IV, Chapter 1, Section 1.6.). Subjective assessments of nasality have been questioned by many speech therapists, such as Buck (1951), Shermann (1954) and Fletcher (1970) (see Part IV, Chapter 1, Section 1.6.). Shermann (1964) has suggested that the evaluation of nasality should be based on tape-recorded speech replayed backwards. According to him, this technique provides a more reliable assessment of severe degrees of nasality.

The control of airflow through the nose has been suggested as a possible measure of relative degrees of nasality (see Part III, Chapter 3), but the reliability of this method is questionable as we have pointed out in the previous chapter, which deals with airflow and the production of nasality.

A more elaborate proposal suggests that it is the relationship between the opening into the oral cavity and the opening into the nasal cavity which is crucial. Kaltenborn (1948) studied this relationship between the area of the nasal and oral ports and the production of nasality, and concluded that

> "Nasality is caused by having too wide an opening into the nasopharynx in comparison with the opening into the oral cavity" (cited by van Riper and Irwin 1958: 241).

This conclusion gave rise to the notion of the oral:nasal ratio as an objective measure for nasality. This statement is also related to the notion of a cul-de-sac resonator in the production of nasality (see Part III, Chapter 2).

The idea of having an objective measurement of nasality as a result of a ratio between the values of two active factors involved in the production of nasality, has been widely accepted among researchers (Warren 1967: 151; Fletcher 1970 and 1972; Daly and Johnson 1974; Heller et al. 1974: 353; Bernard et al. 1975; Clarke 1975a and 1975b). As a matter of fact, many devices have been invented which attempt to display relative degrees of nasality by comparing two parameters like oral/nasal airflow, oral/nasal sound pressure variations, velic opening or relative velic height in relation to airflow or audio signal, and the timing of the occurrence of the oral/nasal feature in relation to segmental articulation, etc. We will consider below some aspects and factors related to the possibility of obtaining oral:nasal ratios.

The measurement of the nasal port during the production of speech is a difficult task. The opening is in practical terms inaccessible to direct observations and very difficult to investigate using techniques so far available, as for example, tomography, endoscopy and fiberoptic observation (see Part IV, Chapter 1). Fiberoptic observation provides the most promising technique, and in the near future, we will have more reliable data about the size, the area and the general configuration of the nasal port.

The first attempt to estimate the functional geometry of the velic opening was carried out by Passavant. He inserted rubber tubes of different diameters in the nasal port to create an artificial velopharyngeal opening when the velum was raised to close the nasal port. He found that a tube 6.8 mm diameter (12.6 mm^2)

"did not appreciably influence speech... a 10 mm thick with an inner cross-sectional area of 28.3 mm^2 gave most of the consonants a nasal character, but the vowels were still not influenced" (cited by Fritzell 1969: 8).

The same technique was used by Schmidt (see McDonald and Baker 1951: 10). Schmidt found that with a tube 6 mm in diameter, speech was not nasalized, but with tubes of larger diameters, speech was perceived as nasalized. Kaltenborn (1948) made measurements of the coupling dimensions and found that with a nasal opening of 1 mm and an oral opening of 11 mm, speech did not sound nasalized at all. With a nasal opening of 8.8 mm and an oral opening of 3.1 mm, speech sounded very nasalized. He concluded that relative degrees of nasality are directly proportional to nasal opening and indirectly proportional to oral opening, with severe nasality being characterized by a wide nasal opening and small oral opening. Björk (1961: 399) measured typical coupling areas and found the following relations: a nasal coupling area of 60 mm^2 was enough to produce slight nasalization; severe nasalization was obtained with a nasal coupling area of 250 mm^2.

An ingenious way of measuring the area of the nasal port was developed by Warren and DuBois (1964; see also Warren 1967, 1976). When the pressure differential across the velic opening (nasal pressure minus oral pressure) and the rate of airflow are known, it is possible to estimate the area of the opening by means of a hydrokinetic equation (see Part IV, Chapter 1, Section 1.3.). Warren and DuBois modified the equation slightly and thereby found the technique reliable and useful. Different degrees of nasality assessed auditorily were compared with the area of the nasal port and they found the following correlation:

orifice area:

0	-	20 mm^2 :	adequate closure
21	-	40 mm^2 :	slight inadequacy of velic closure
41	-	100 mm^2 :	moderate inadequacy of velic closure
above		100 mm^2 :	gross inadequacy of velic closure

(see Warren 1967: 151). Warren investigated the correlation between amount of nasal airflow and area of velopharyngeal opening, and found that up to 20 mm^2 of velopharyngeal opening, the coefficient was as high as .93; nasal airflow, hence, being linearly related to velopharyngeal opening size. But with openings larger than 20 mm^2, the correlation coefficient dropped to .43 . So, according to his findings, the 20 mm^2 opening size is a critical threshold. Warren (1976: 128, 130) points out that even a stop can be produced without nasality with a nasal port opening of 20 mm^2, but a nasal sound must have an opening area larger than 20 mm^2 in order not to be heard as denasalized.

Another method of assessing different degrees of nasality, consists of the establishement of some sort of ratio between different degrees of nasality assessed subjectively, and acoustic measurements of certain parameters such as sound pressure variations picked up by microphones. Weiss (1954) found a correlation of 0.945 between sound pressure and degrees of nasality (judged subjectively). Shelton et al. (1967), however, found a very low correlation in a similar investigation.

Another technique in use in the field of speech pathology is described next. Two microphones pick up the sound pressure variations from the mouth and from the nose separately. Then, special equipment processes the two types of variations and gives a result representing the average of the two recordings as an oral:nasal ratio. From the recordings of many subjects, it is possible to set up reference points beyond which speech is classified as slightly, moderately, or severely nasalized (Fletcher 1970, 1972; Daly and Johnson 1974; Bernard et al 1975; Clarke 1975a and 1975b). Serpa-Leitão and Galyas (1974) are developing another technique which compares the signal from the nose with the signal from the larynx. After a special computation, the instrument displays a number signifying the different degrees of nasality. This point is discussed more fully in Part IV, Chapter 1, Section 1.6.

In résumé, we can say that there are five parameters involved in the production of nasality that are suitable for using in order to set up ratio values for the oral:nasal feature, and consequently, to relate different perceptual degrees of nasality with the action of the velopharyngeal mechanism. The five parameters are:

a) <u>nasal opening</u>: the size and shape of the nasal opening varies relative to the position of the velum, thus producing different degrees of integration of the nasal cavities with the oral tract.

b) <u>velic height:</u> the velum assumes different vertical positions for the articulation of different speech segments.

c) <u>airflow characteristics</u>: the movements of the velum are responsible for the amount of air shunted into the nasal cavity and for some supraglottal pressure variations.

d) <u>acoustic coupling</u>: the controlled movements of the velum are the most important manner of allowing or avoiding nasal resonance in the production of the linguistic segments of languages.

e) <u>timing of the occurrence of the oral/nasal feature linguistically</u>: velic movements must be performed in such a way as to produce the nasal feature in a controlled manner, so that a nasal stop is differentiated from an oral stop, and a nasalized vowel from the corresponding oral vowel, and so on, according to linguistic requirements. The velum, in other words, needs to work in close synchronysm with labial and lingual articulations and with voicing.

As we said earlier, these five parameters are all suitable for use in setting up ratio values for the oral/nasal feature.

The procedure of setting up ratios has the advantage of being controllable, constant and measurable when a fixed point is given. This fixed point, as the basis of the measurements, is the crucial point, the vital and most important factor in assessing relative degrees of nasality (van Riper and Irwin 1958: 246; Laver 1975: 182). However, this reference point must be established with the help of auditory judgements. The criterion for establishing it must take into account an average from a large population in order to be very helpful (Clarke 1975b). The ratios need to be flexible according to different situations, as some experiments have shown. For example, there is some evidence to support the claim that the female population presents higher ratio figures for nasalization than the male population under the same conditions (Couniham and Pierce 1965; Clarke 1975b). Moreover, Clarke (1975b) found a deviation of about 20 % in the oral:nasal ratio in spontaneous speech when compared with reading tasks.

Although in practice, all types of measurements using a ratio relationship have been valuable, principally in the diagnosis and therapy of nasality, as a final remark, we must add that it is rather simplistic to think that any kind of oral:nasal ratio is a realistic and objective measure of nasality. In fact, the oral:nasal ratio may be used as a convenient way of controlling nasality in some way and it is specially efficient in extreme cases.

Chapter 5 : The Articulatory Function of the Velum

From the description given so far, it may seem as if the velum performs a simple and well defined function in the production of speech. A review of the literature, however, will show a much more confusing picture. Van Riper and Irwin (1958: 388) point out:

> "There is probably no basic mechanism in the entire speech process that has attracted more speculation and resulted in more controversy than the velopharyngeal mechanism".

For example, the fact that an oral sound can be articulated with the velum not making a complete and tight closure against the pharynx is quite common in the speech pathology literature, but is not usually acknowledged in the phonetic literature. On the contrary, such a statement has been refuted by some phoneticians as being not accurately investigated in some way or another, principally in perceptual terms. Nevertheless, there is a lot of evidence from experimental investigations to confirm that it is possible to have oral sounds without a complete velopharyngeal closure: Nusbaum et al. (1935), Kantner and West (1941), Heffner (1949), McDonald and Baker (1951), Buck (1951), van Riper and Irwin (1958: 392-393) and Laver (1975). Van Riper and Irwin, after recognizing that complete and tight velopharyngeal closure is not crucial in the production of all oral sounds, remark that

> "The point we are trying to make is this: it is naive to suppose that closure must be airtight in the production of all non-nasal sounds; but it is equally naive to believe

that the degree of closure is not important. In this book, therefore, we have employed the concept of FUNCTIONAL CLOSURE. By this term we mean a closure that is complete enough to avoid the direct auditory consequences of open nasality. We are prepared to concede that the tightness of the seal which is necessary to achieve functional closure may vary with other aspects of the speech act, such as, for example, tongue position or the openness of the nasal passageway. But we contend that no matter how much these other variables may be manipulated, some degree of closure will still be necessary at the velopharyngeal constriction, if speech of completely normal acoustic effect is to be achieved. Our concept of functional closure then, is based on auditory rather than anatomical criteria" (van Riper and Irwin 1958: 393).

Moll and Shriner (1967) suggested that the velic mechanism may be interpreted as having only two movements: one ON, when muscular forces elevate the velum, and the other OFF, when the velum is lowered. They explain the different elevations of the velum for different speech sounds, as being the result of temporal constraints or as being caused by the mechanical requirement of sequences of sounds. They write:

"It seems more reasonable to attribute the differences in velar (sic) elevation between high and low vowels to changes in the degree of restriction on velar movements by tongue position than to contend that the speaker adjusts velar muscle activity to achieve the degree of velopharyngeal closure required for producing a given vowel without nasal quality. It also is possible that other mechanical factors besides tongue position may affect velar elevation. For example, Ackermann (1935) and Podvinec (1952) suggest that movements of the pharynx and larynx may be important in determining velar position, since the velum is attached to both of these structures by the palatopharyngeus muscles. Velar position also may be affected by variations in

> intraoral breath pressure during speech; the pressures built up in the oral cavity during fricative and stop sounds might tend to force the velum somewhat higher" (Moll and Shriner 1967: 65-66).

They also admit that neuromuscular effort can account for the different positions assumed by the velum. Finally, they conclude that the velum

> "may not be an articulatory structure in the sense as the tongue, jaw and lips" (Moll and Shriner 1967: 67).

Moll and Shriner based their investigation on cinefluorographic data in an analysis of articulatory durations. Investigations based on EMG data of the structures involved in the velopharyngeal mechanism did not lend support for Moll and Shriner's theory. On the contrary, the evidence showed that different positions of the velum are controlled by proportionally different levels of neuromuscular activity (Lübker 1968; Fritzell 1969: 68; and Benguerel et al. 1977b: 166).

Although some writers in the phonetic literature admit different degrees of velic elevation during speech (Abercrombie 1967: 43; Catford 1977: 139-140), nevertheless, it is common practice to incorporate only two positions of the velum in the phonetic description of segments: segments with velic closure or segments without velic closure. Some people believe that different degrees of velic lowering can be used to produce different degrees of nasality, independently from the nature of the segments involved. Thus, according to this point of view, the velic function has a mode of articulation with two polar positions, producing either oral sounds when there is velic closure, or sounds with nasality when there is no velic closure.

However, if we carry out a more extensive review of the works on nasality and its characteristics, starting with the experimental investigations performed in the last century up to the most recent publications on this subject, it is clear that there is remarkable agreement among writers about the fact that the velum exhibits different positions or different degrees of elevation for different activities, and more precisely for different segments during speech. For example, Condax et al. (1976) studied several X-ray records of the velum and came to the conclusion that the velum has five distinct positions in relation to the flat floor of the nasal cavity, during speech. The positions are presented schematically in Fig. 13.

A comprehensive survey of the articulatory function of the velum, incorporating data recorded using a variety of techniques allows us to establish a velic scale such as the one proposed below:

NEUTRAL	highest position	1. blowing
VELIC	of the velum	2. voiceless stops
SCALE	↑	3. voiced stops
		4. voiceless fricatives
		5. voiced fricatives
		6. oral close vowels
		7. oral open vowels
		8. nasalized close vowels
		9. nasalized open vowels
	↓	10. nasals
	lowest position	11. breathing
	of the velum	(respiratory position)

The data from which the proposed scale is derived is based on direct observation (fiberoptic, endoscopic) of velic height, indirectly assumed positions of the velum, inferred from aerodynamic investigations, X-ray pictures and films, EMG recordings of the activity of the velopharyngeal muscles, mechanical recordings of velic movements (with strain gauges), etc. It is well accepted that the highest position assumed by the velum occurs during blowing (Kaplan 1960: 190). It is also common in the literature, to find reports saying that stops have a higher velic position than fricatives

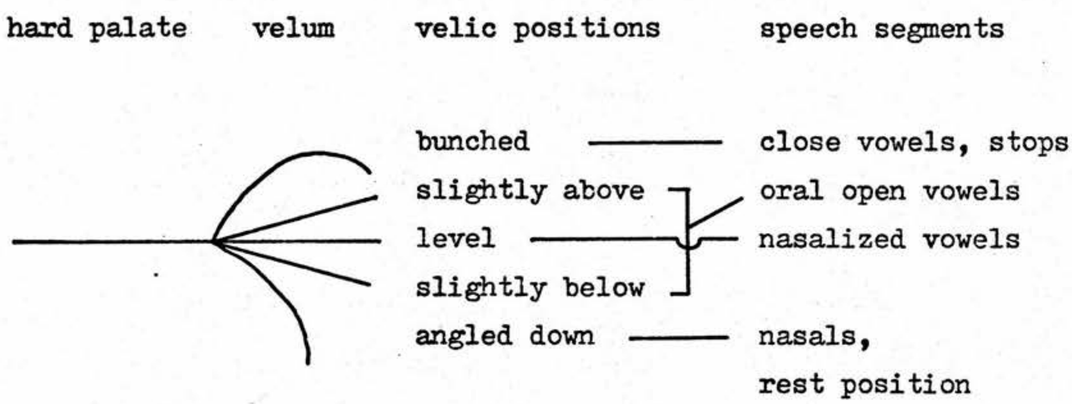


Fig. 13 Schematic representation based on X-ray records of different positions of the velum during speech as reported by Condax et al. (1976).

(Calnan 1955: 15-16); and both have a higher velic position than vowels, even when the velum is closed (MacNeilage 1972: 20). According to Bell-Berti and Hirose (1975), the velum has the tendency to move to a higher position for voiceless consonants than for voiced ones. Vowels show a particular scale of positions of the velum. There is a lot of support from different experiments to show that a close vowel has the highest position of the velum, and an open vowel has the lowest position of the velum (within the vocalic range of velic positions). Other categories of vowels have intermediate positions between these two extremes. The velic scale is more evident when the vowel is typically nasalized, although it is also true, at least in general terms, for the oral vowels as well, principally when we consider their production in terms of EMG activity of the velopharyngeal muscles (Lübker 1968). The nasals are said to have even lower positions on the velic scale than the nasalized vowels. The lowest position of the velum is typical of breathing or of the so-called rest position of the velum (which I prefer to call the respiratory position of the velum). For more detail of different velic heights, see: Harrington (1944), van Riper and Irwin (1958: 241), Kaplan (1960: 183-184), Moll (1960), Zemlin (1968: 309-310), Fritzell (1969: 64), Karabinos (1973: 13, 24-25) and Clumeck (1976).

The acoustic and perceptual investigation of nasalization has shown that phonetic elements occupying the higher positions on the velic scale have more susceptibility to nasalization than phonetic elements which occupy the lower positions. House and Stevens say:

> "A small degree of coupling changes a vowel like [u] into a nasal sound, while almost three times as much coupling is needed to nasalize [a]. Small amounts of nasal coupling produce marked changes in the spectra of

> the vowels [i, u] that in turn serve as cues for the identification of nasality; a much greater degree of coupling is needed to produce comparable changes in the spectrum of [a] and thereby to achieve a comparable level of nasality" (House and Stevens 1956: 228).

(see Part V, Chapters 1 and 3). Similar variations relating to vowel height and EMG activity have also been found, as reported by MacNeilage (1972: 19). He says:

> "Combined cinefluorographic and electromyographic studies (Lübker 1968; Fritzell 1969) have shown correlation coefficients of approximately 0.8 between amount of velar elevation and amplitude of EMG activity in the levator palatine muscle. Velar elevation and levator EMG amplitude have also been regularly shown to be directly proportional to vowel height, although not so regularly related to the front-back dimensions of vowels (Bell-Berti 1971). Lübker is probably right in postulating that the higher EMG levels for high vowels reflects a maneuvre compensating for their greater susceptibility to nasalization".

Summarising the suggested velic functions discussed so far, we may say that two types of general explanation have been put forward to explain why the velum assumes specific positions for particular phonetic segments. One explanation is that the velum assumes specific positions for different segments because of the relatively different acoustical susceptibility of different segments to nasalization and the consequent perception of nasality in speech segments. So, a close vowel has a higher position of the velum than a more open vowel because if the close vowel assumes the velic position typical of the open vowel, it will be perceived as a nasalized vowel. In this way, the velum can assume a lower position for open vowels without consequent nasalization, but it cannot do so for a close vowel, due to the inherent acoustical nature of those segments. The second explanation, put forward by Moll and Shriner (1967), says that the velum has, in fact, only two extreme positions: one well closed and the other well open. The intermediate positions of the velum found in speech are due to constraints on the ability of the velum to adjust to one of the polar positions. This happens, they claim, because of the fact that speech moves too fast requiring antagonistic movements of the velum faster than it can move. Therefore, the resulting positions of the velum can be easily predicted by the phonetic environment.

We have, therefore, two models of velic movement that we can call the acoustical model and the polar model. The first is examplified by by MacNeilage's position (1972: 19), and the second represents Moll and Shriner's position (1967).

It seems, however, that the phenomenon is not explained completely either by the acoustical, or by the polar model. In an integrated theory of speech production, it seems true that the velum assumes specific positions for particular phonetic segments also because of the concurrent neuromuscular constraints which control the velum in synchronism with other neuromuscular activities required in the production of different types of segments. In this way, the velum is an articulator of the same type as the tongue, the lips and the vocal cords. Moreover, with each phonetic element having an inherent velic position, the assumption that it is possible to produce different degrees of nasality by having different positions of the velum is better justified. In other words, the velum has to assume different positions during speech because of neuromuscular constraints, the acoustical nature of the segments, and the phonetic environment in connected speech, and this makes the velum an articulator of the same nature as the tongue, the lips and the vocal cords. For this reason, it is interesting to suggest a NEUTRAL VELIC SCALE, whose order corresponds to the articulatory necessity for the velum to assume different positions as a function of specific phonetic segments in the production of normal speech. An example of such a neutral velic scale was presented earlier.

The neutral velic scale may be used as a model of articulation of the velum and as such contributes to a better understanding and a better analysis of the phonetic nature of nasality. In this case, for example, the speech of an individual can be investigated instrumentally in terms of any of the five parameters which contribute to an oral/nasal ratio. The recording of nasal airflow, for example, shows fluctuations either in normal voice or in nasalized voice (see Part VI, Chapter 1). In nasalized voice, the nasal airflow trace does not display a constant and straight line at a steady level, but varies according to the nature of the segments involved. In normal voice, the amount of nasal airflow for each (nasal) segment follows a pattern predicted by the neutral velic scale (see Fig. 27 in Part VI, Chapter 1); but, in nasalized voice, the amount of nasal airflow for segments shows a displacement downwards in the velic scale, i.e. increased nasal airflow. The evaluation of nasal airflow in this way, is one of the possibilities that one can use to assess nasality.

The correlation between the articulatory velic scale suggested earlier and other possible scales, derived from measurements of velic activity, such as oral:nasal ratios, needs further investigation.

The new suggested model, which we can name the articulatory model of velic functioning shows that nasalized voice is a disruption of the scaling order towards a more open position of the velum for certain segments at least (see Part VI, Chapter 1, Section 1.2.5.).

Conversely, when the velum assumes closer positions than the predicted positions required for normal speech, the result is denasalized voice. The degree of denasality will be proportional to the distance the velum departs from the required positions in the neutral velic scale which is responsible for the production of normal speech.

Investigations of oral/nasal airflow characteristics, carried out by the author (see Fig. 27 in Part VI, Chapter 1, and Figs. 35 and 36 in Part VI, Chapter 3), indicate that nasalized voice does not present a consistent open nasal port, nor a constant open position of the velum for all segments. On the contrary, a constant fluctuation in the airflow level with the corresponding variability in the nasal port area was found, as noted before. Consequently, the severity of the nasal quality in the voice of certain individuals or the degrees of nasalization for linguistic segments will increase proportionally to the displacement of the velic position for the phonetic segments downwards on the velic scale. The opposite is also true in relation to the process of denasalization. So, according to the explanation suggested, different types of nasal quality may be produced when different individuals with nasalized voice use different scales of velic activity in their speech.

Languages with nasalized vowels are the most susceptible to variation of the velic scale that characterize velic height in speech for normal voice, especially when the language has different degrees of nasalization playing a linguistic role in the system of the language (see, for example, Merrifield 1963: 5, 14). In the latter case, what happens is that some segments are placed differently on the velic scale, the more nasalized occurrences occupying a lower position on the scale. Nihalani's (1975) investigation of Sindhi supports this hypothesis. He observed that, in Sindhi, voiced and aspirated voiced stops are slightly nasalized, without being confused with the nasals.

There is some evidence to support the notion that the nasal quality which accompanies nasals and nasalized segments in languages linguistically, differs from the nasal quality which characterizes an individual voice. One sentence with almost all segments nasalized in a language where nasality is linguistically required, sounds different when said normally, from a performance of the same sentence with a nasalized voice quality. An example of such a sentence from Brazilian Portuguese, would be:

"Minha mãe não vinha na caminha".

['mĩɲa 'mɜ̃ĩɲ 'nɜ̃õ 'vĩɲa na kɜ̃'mĩɲa]

A relatively open nasal port produces severe nasalization on close vowels and consonants, but a much less severe degree of nasalization on open vowels, everything else being equal. This shows that the velum has modes of articulation specifically determined by different speech segments to produce what we accept as normal voice. When this order is disrupted, the result will be either slight or severe nasality or denasality according to the extent and direction of the disruption.

PART IV : TECHNIQUES OF STUDYING NASALITY

Chapter 1 : Techniques of Studying Nasality: a Historical Review

It is the intention of the present chapter to draw together the references to studies of nasality mentioned elsewhere in this thesis in a historical review. A review of the techniques used by different investigators in experimental studies of nasality is useful for a better understanding of the results reported by these investigators.

1.1. Anatomical Studies

Before the 15th century, only the uvula was mentioned in publications about the anatomy of the head in relation to the velopharyngeal mechanism. The first researcher to pay attention to the velum in anatomical terms was Leonardo da Vinci (1452-1519), who made anatomical drawing of the 'palato mobile' (movable palate). Later, in 1561, Fallopius, a professor of anatomy in Padua, described the anatomy of the velum for the first time. However, true studies of the anatomy and physiology of the velopharyngeal mechanism started only in the 17th century. Fritzell comments:

> "The soft palate cannot be directly observed in normal subjects during speech, and the velopharyngeal mechanism apparently remained unknown until the seventeenth century" (Fritzell 1969: 69).

From the 17th century to the present day, there have been many works specially dedicated to the investigation of the anatomy and physiology of the soft palate, and the relationship between the velopharyngeal mechanism and the production of speech.

In the second half of the 19th century, starting with pioneer work by Czermak, a great amount of experimental work was carried out to investigate the muscles of the velum and their function. One of the most important researchers was G. Passavant (see Part II, Chapter 2, Section 2.3.). He studied the elevation of the velum during speech with a rhinoscope. He also investigated the nasal port during the articulation of some vowels by means of a thread which passed through the nose, round the velum and out again through the mouth. When studying the velopharyngeal mechanism in cleft palate speakers, Passavant observed a muscular bulging moving the posterior pharyngeal wall forward during velic closure. This muscular protuberance which occurs in some individuals, received the name of 'Passavant's cushion' (or pad, ridge, etc.).

Study of the anatomy and physiology of the velum was carried out mainly through dissection of cadavers and direct observation of the exposed structures in individuals with facial defects. Studies from dissections of cadavers have been more recently reported by McMyn (1940), Harrington (1944), Podvinec (1952), Bosma (1953), Bjuggren and Fant (1964), Fritzell (1969) and Dickson and Dickson (1972). The function of the velopharyngeal mechanism has been observed in individuals with facial defects since the 19th century: Hilton (1836), Ackermann (1935), Harrington (1944), Podvinec (1952), Bosma (1953) and Calnan (1955).

1.2. Physiological Studies

Only in the 17th century was the function of the velopharyngeal muscles understood. The first to attribute an articulatory function to the soft palate was Amman in 1700, as reported by Fritzell (1969: 7). He observed that the soft palate 'controls the diversion of the voice' which passes out through the nostrils.

For a long time, the function of the velopharyngeal mechanism was inferred from the anatomical structure of the area. The movements of the velum were explained in relation to the inferred capacity of relevant muscles to produce the necessary movements of the velum during speech and other processes. Modern research on the physiology of the velopharyngeal mechanism, however, has used electromyographic recording of the electrical potentials of the muscles during the period of muscular activity. An important aspect of EMG recording is that the relationship between EMG activity and the time course of the movement of the velum can be investigated. It must be pointed out that an EMG recording is an indirect method of showing the mechanical activity of a muscle. The amplitude of the mechanical movement is not necessarily related to the corresponding amplitude of the electrical myographic recording (van den Berg 1962: 97). However, electromyography gives useful information about muscular activity, usually as a function of the duration of its occurrence.

Fritzell (1969: 18-20) reviewed eleven works on the activity of the palatal muscles using an EMG technique. The first was carried out by Li and Lundervold in 1958. Fritzell was, however, the first to investigate all the muscles of the velopharyngeal mechanism. In general, we find, in the literature, studies of the levator, tensor or superior constrictor. In more recent works, the investigations are concentrated on the levator and palatoglossus in particular. Very recent EMG studies of the velopharyngeal mechanism in speech have been performed by Lübker et al. (1972a, 1972b), Bell-Berti (1973, 1976), Bell-Berti and Hirose (1975) and Benguerel et al. (1977b).

The function of the velopharyngeal mechanism has also been investigated in experiments combining EMG recordings with simultaneous fiberoptic motion pictures (Bell-Berti and Hirose 1975;

Benguerel et al. 1977b), or with cinefluorographic films (Lübker 1968; Fritzell 1969). The investigators have been compelled by recent EMG data to review some ideas about the physiology of the velopharyngeal mechanism, in particular the role played by the muscles controlling the nasal port during speech. For further discussion, see Parts II and III.

1.3. Aerodynamic Studies

The first report on the investigation of the characteristics of airflow from the nose in speech was done by Brücke in 1856. He used the flame of a candle to monitor nasal airflow. The first attempt to measure nasal airflow seems to have been done by Rosapelly in Rousselot's laboratory in 1888. His idea was to study the airflow from the nose with a kymographic system, borrowed from the physiologists. Ever since, the kymograph has been one of the most valuable instruments for studying the aerodynamics of nasality.

The kymograph has its origin in Ludwig's 'kymographion' originally used to measure blood pressure. The principle was to record a vibrating movement with a needle scratching a moving smoked paper. M. Marey and M. Chauveau considerably developed the technique by introducing the so-called Marey-tambour with the scribing needle attached to it. Rousselot introduced a number of improvements to make the equipment suitable for phonetic research. At the end of one rubber tube, a mouthpiece similar to a gas mask was attached to pick up the airflow from the mouth and at the end of another tube, a nasal olive, to pick up the airflow from one nostril. The drum designed originally with a clockwork mechanism changed to an electrically powered cylinder with better accuracy in the rotation. Soon, the cylinder was enlarged and it became possible to get, simultaneously, graphic records of the movements of different organs and processes during speech, such as laryngeal vibrations, chest movements, lip movements, airflow from the mouth and from the nose. Phonetics now had a very powerful technique for describing speech sounds experimentally in some detail.

Rousselot (1924: 94-95) reported another application of kymography in the physiological investigation of velic movements. He called the technique 'explorateur du voile du palais' (explorer of the velum). The technique involved a thin metal ring with a small bar fixed vertically to it which was placed below the velum inside the subject's mouth. When the velum moved up or down, the small bar following it transmitted the movement through the ring to the needle which then recorded on the paper as a variation of amplitude. A similar technique involving a strain gauge transducer (Moller et al. 1971) is used today to investigate movements of the velum. Instead of the ring, a spring is fixed on a back tooth and the movements of the velum moving the spring are recorded as variations of voltage.

Although the kymograph could record not only the amplitude of the movement, but also the vibrations themselves within a certain range, and several other parameters simultaneously, nevertheless, it was a fairly crude instrument for studying the complexities of speech.

A significa~~tive~~nt development in the kymographic technique was introduced by A. de Lacerda, who in 1932 designed the 'polychromograph'. This equipment overcame two main limitations of the old kymograph: the difficulty of controlling the tenseness of the tambour membrane and the system of scribing on a smoked white paper. The new equipment which later received the name 'chromograph' used a special ink-jet recording system on common paper, the paper being driven by an electric motor at constant high speed. The chromograph could pick up vibrations up to 5,000 cps, and is the origin of modern mingographic systems. Lacerda also invented the 'tonometric triangle' which is a mechanical system for reading the acoustic values of 'tones' (i.e. acoustic energy) from a chromographic recording.

The electrokymograph associated with the chromographic system is nowadays replaced by an aerometer, and the Marey's tambour has been replaced by a photoelectric sensor.

The Electro-Aerometer, designed by S. Smith and B. Frøkjaer-Jensen in Copenhagen, around 1960, consists of a face mask made of soft rubber edges, with four airflow transducers and a contact microphone; the innovation being the system by which the airflow variations are picked up. The airflow, passing through a rubber valve, produces different degrees of opening. In the manual describing the apparatus, they say that 'the degree of valve opening is registered by means of a light beam transmitted through the open valve and picked up by a photo diode'. The location of the valves allows egressive and ingressive airflow during speech to be registered separately. The recording graphs are printed by a multichannel mingograph and allow one to record very long pieces of speech continuously (Smith 1972; see Part VI, Chapter 1).

A similar technique to the aerometer was developed by Kozhevnikov and Chistovich (1965). They recorded the airflow from the nose with a horn-type unit which is a photoelectric speaker pick-up, with an olive-shaped rapid response thermoanemometer pick-up. Both units were integrated with nine other units for simultaneously processing acoustical and articulatory parameters of speech. Kozhevnikov and Chistovich were primarily concerned with the investigation of the dynamic variations of different speech parameters as a function of the time of their duration.

The most recent studies on the aerodynamics of nasality have employed more sophisticated technique, although it is basically similar to kymography. The improvements are related to the manner of measuring the properties of the airstream without interfering with it. Instead of the tambour or the photoelectric diode, a warm-wire anemometer or a pneumotachograph is used with a differential pressure transducer. The warm-wire anemometer has two filaments, one heated and the other unheated. When the airstream passes, the heated filament is cooled, producing an alteration in the electrical resistance which is amplified and printed out. The change in voltage is proportional to the amount of airflow. Warren (1967: 110) observes:

> "There is less restriction on articulatory movements with the warm-wire anemometer since a face mask is unnecessary. However, the anemometer has poor linearity and does not differentiate between ingressive and egressive airflow and, for this reason, is less popular than the heated pneumotachograph".

The pneumotachograph is one of the best devices available for measuring airflow. It consists of a fine wire mesh screen which offers minimal resistance to the airstream. The mesh screen causes a small pressure drop which is linearly related to the rate of the airstream. The pressure differential is picked up by a differential pressure transducer, amplified and printed out by a mingograph. The pneumotachograph records egressive and ingressive airflow on the same trace, and for this reason it has a perfect zero point (baseline) and an accurate measurement of the flow (see Part VI, Chapters 2, 3 and 4). More information about flowmeters in general can be found in Fry et al.

(1957), Warren and DuBois (1964), Lübker and Moll (1965), Subtelny et al. (1966) and Warren (1976).

Airflow characteristics are usually assumed to be a possible measure of nasality and velopharyngeal competency. However, as we already discussed (Part III, Chapters 3 and 4) there is no direct relationship between nasal airflow and nasality, although, a relatively high and controlled amount of nasal airflow can be used as an indication of the occurrence of segmental nasality. Nasal airflow records must always be accompanied by an auditory judgement of speech, especially when nasality is involved. For further discussion on this question, see Warren (1967, 1976) and Warren and DuBois (1964). Warren (1967: 148) observed:

> "... in order to infer that nasal emission is, in fact, a measure of palatopharyngeal competency, one must show that nasal leakage is related to size of the velopharyngeal orifice".

Warren pointed out that the velopharyngeal orifice size could be estimated from simultaneous recordings of the pressure drop across the nasal port and the measurement of the airflow rate passing through it. The pressure drop across the nasal port can be estimated from recordings of oropharyngeal pressure minus nasopharyngeal pressure. Warren calculated velic orifice area according to a modified equation based on the theoretical hydraulic principle (hydrokinetic equation reported by Gorlin in 1951). The equation is:

$$\text{orifice area} = \frac{\text{volume rate of nasal airflow}}{K\sqrt{2\left(\dfrac{\text{orifice differential pressure}}{\text{density of air}}\right)}}$$

where, density of air = $0.001\ \text{gms/cm}^3$; K = 'correction factor' with a constant value = 0.65: see Warren (1967: 156). The constant factor K is necessary to compensate for deviations from real flow (turbulent, non-uniform and rotational) which is considered to have a 'fictitious steady motion' in the calculations (see Part III, Chapter 4).

1.4. Studies of Velic Movements

The first comprehensive study of the velopharyngeal mechanism was published by Dzondi in 1831. As was pointed out earlier, many people studied the velum in the last century. In 1836, Hilton started a series of investigations which studied the movements of the velum from above (nasopharynx) in subjects with facial defects (patients with a wide opening through the lateral wall of the cheek and nose, so that the nasopharynx and sometimes even the mouth could be seen directly from outside) (Gentzen 1876; Bloomer 1953). Passavant (1863) investigated the movements of the velum with a rhinoscope. Gentzen, in 1876, made a kymographic recording of the movements of the velum in a subject with a facial defect (see Sections 1.1. and 1.2. of the present chapter). Czermak (1857, 1858 and 1869) used many different devices to show the movements of the velum, such as a special wire probe inserted through the nose, a cold mirror under the nostrils and even the technique of filling the nasopharynx with water. He was the first to state that the velum assumes different degrees of elevation according to the vowel height, forming the following series: [a - e - o - u - i] in other words, the velum position is directly related to vowel height. Passavant found similar results in his experiments (see Part III, Chapter 5).

The study of velic movements was improved considerably with the innovation of X-ray. This technique has different names, such as cephalometric X-ray, cephalometric roentgenology, cephalometric laminography, cephalic radiography, cinefluorography, cineradiography, tomography, etc. (Subtelny et al. 1957; Björk 1961; Zemlin 1968: 332-338). The technique appeared at the end of the 19th century and the first research on speech using X-rays was published by Scheier in 1898 (Subtelny et al. 1957: 179). Scheier also described the soft palate and velic closure (Fritzell 1969: 9). The first X-ray film showing the dynamic action of the articulators during speech was reported by Gottheimer in 1929. In 1955, Skoog and Nylén made use of image intensifiers to obtain a clearer picture of the soft palate and other structures during speech. Extensive studies employing X-ray techniques have been done since the technique first appeared towards the end of the last century (Carmody and Holbrook 1937). But with increased awareness of the danger of radiation, the massive exposure of subjects to X-rays, typical of the studies at the beginning of this century, was no longer possible. Today, however, new instruments with better image projection and lower levels of radiation are again providing the possibility of more extensive investigation with this technique.

The traditional single exposure cephalometric X-ray is still very convenient for studying the vocal tract. The lateral projection is the most suitable for the study of articulations, but to investigate the movements of the lateral pharyngeal walls during phonation, Zwitman et al. (1974: 370) suggest a submentovertical projection. Tomography is the best technique for studying the configuration of the nasal port (Björk 1961).

To make measurements from X-ray pictures is not an easy task because of the complexity of the structure of the skull. Physiologists have developed a series of reference points and lines to guide the readings. An explanation of these can be found, for example, in Zemlin (1968: 332-338). He also describes how to make measurements of soft palate length and thickness, as well as the vertical height and horizontal depth of the nasopharynx.

New perspectives in the investigation of the velum and adjacent structures have been given by the use of ultrasonic techniques. Zagzebski (1975), for instance, studied the movements of the lateral pharyngeal walls using this technique. The technique consists basically of a pulse-echo ultrasonic tranducer that emits a pulsed sound beam (2.25 MHz) and detects the echoes, originating from specific structures within the neck. The measurement is made in the following manner:

> "An echo from the lateral pharyngeal wall is detected after a short delay time, which is proportional to the external neck wall-lateral pharyngeal wall distance. By recording the depth of origin of this echo over an extended time interval, a time-motion plot of the lateral pharyngeal wall position is obtained" (Zagzebski 1975: 309).

Zagzebski recorded the movements of the lateral pharyngeal wall at the level of velic closure and at the mid oropharyngeal region, and found that the walls have independent patterns of displacement at the two levels during speech (see Part II, Chapter 2, Section 2.2).

Another technique for studying the movements of the velum was designed by J.J. Ohala (1972), which he called the Nasograph. The nasograph consists of a thin clear plastic tube acting as a probe, with one end closed. An electric light source and a photoelectric sensor are fixed inside the tube. When the probe is introduced via the subject's nose until the closed end reaches the oesophagus, the light source remains in the pharynx and the sensor in the naso-pharyngeal cavity. Different degrees of opening of the nasal port can be picked up by the photoelectric sensor and recorded as variations in voltage. These readings can then be compared with other articulatory or acoustic recordings made simultaneously (see Clumeck 1975).

Another similar technique to investigate the movements of the velum using a photoelectric nasal sensor in a probe has been reported by Condax et al. (1976). They recorded the sound and the light probe signal simultaneously on a two channel tape recorder. The signal from the light probe passes first through a voltage-to-frequency converter, then both signals are fed into a spectrograph to produce a spectrogram where the light probe signal appears as a superimposed record in relation to the spectrum of the sound. The light signal is calibrated to appear as a line varying between 2kHz (baseline) up to 8 kHz (upper limit). The probe in this case is a fiberoptic bundle to which an external photoelectric sensor is attached to record variations in the reflected light of the probe. The calibration is described as follows:

> "The signal from this receptor (photoelectric sensor) is set so that light reflected from a surface far from it is too weak to move the signal above the baseline, and light reflected from closer surfaces shows signals above baseline up to a convenient limiting value" (Condax et al. 1976: 174).

To make the recordings, the probe is inserted into one of the nostrils with the end at the posterior nares (see Part III, Chapter 5).

Endoscopes have been used since the 19th century to observe velic movements and the configurations of the nasal port. A very interesting piece of research using an endoscope, was conducted recently by Zwitman et al. (1974). They used a 6 mm diameter endoscope with a fiberoptic source of light to allow the necessary illumination. The endoscope was inserted into the mouth of the subject and they took pictures of the nasal port during the articulation of isolated sounds. The pictures from a large number of subjects indicated four different types of velopharyngeal closure. (More detail about their findings can be seen in Part III, Chapter 2, Section 2.2.).

A fiberoptic bundle is a probe which can transmit a cold light beam following the bends of the probe. This is done by thousands of very small mirrors placed inside the probe. The image conducted by the returning light beam can be seen in a special viewfinder. Because the technique is very new, only few works have been carried out where fiberoptic observations of velic movements were recorded; see, for example, Bell-Berti and Hirose (1975), Benguerel et al. (1977a). This technique has a very promising future in research of the velopharyngeal mechanism.

The synchronized integration of different techniques has proved to be the best way of studying the velopharyngeal mechanism and nasality (Moll 1960; Björk 1961; Warren and DuBois 1964; Lübker and Moll 1965; Kozhevnikov and Chistovich 1967; Lübker 1968; Fritzell 1969).

1.5. Acoustic Studies

The acoustic investigation of nasality is very complex and not easy even with sophisticated equipment (see Part V). The coupling of the nasal cavity to the oral tract introduces many problems in the analysis of the spectrum. This is the reason many investigators have decided to study nasality by developing mathematical models of the vocal tract which could provide them with data on the phenomenon of nasality with the advantage of being tested through an electrical analogue (see Part III, Chapter 2, Section 2.4.). Flanagan says:

> "The functioning of the combined vocal and nasal tracts is difficult to treat analytically. The coupled cavities represent a relatively complex system. Precise calculations of their interactions can best be done by analog or digital computer simulation" (Flanagan 1965: 68).

During the past 20 years, many analogue models of the vocal tract and speech synthesizers have been developed and have proved to be amongst the most useful tools for phonetic research. The majority of the acoustic information on the effect of nasalization that is accepted as reliable, was obtained by means of this technique. More discussion about the construction of analogue models of the vocal tract and the production of nasality can be found in Part III, Chapter 2, Section 2.4.).

A simple way of studying nasality as a function of time can be carried out by recording the audio signal output from the nose and from the mouth together with other articulatory parameters. Lehiste (1964) used two microphones to pick up the oral and nasal signals which were recorded on a two channel tape recorder. Using a multi-channel oscillograph, a simultaneous print-out was obtained of the nasal and oral audio signals and the nasal intensity variation. The three graphs, when compared simultaneously along the time axis, allow the effect of nasalization upon segmental boundaries to be analysed.

An acoustic analysis of nasality was done by O. Fujimura (1961, 1962) using an analysis-by-synthesis approach (see Part V, Chapter 2). The intensity-frequency-time representation of the nasals was quantified on a 'digital spectrogram' for analysis by computer. The quantification was made by passing the signal through a special set of 36 filters, covering the frequency range of 100 up to 7,200 cps. The readings were sampled at 8.3 msec invervals, and quantified in 1 dB steps. The data were stored on punched paper. The analysis of pole and zero distribution for the vocal tract transfer function was carried out by matching a trial spectrum of a calculated synthetic pole-zero distribution to the speech spectra. The goodness of fit between the two spectra was computed. In this way, the movements of pole and zero distribution as a function of time could be investigated and the acoustic characteristics of nasal resonance could be defined. A similar technique of graphical spectrum matching of mathematically derived standard envelopes with real speech samples was used by Fujimura and Lindqvist (1964) to study the nasal quality and the effect of nasalization on vowels.

Although much of the information available on the acoustics of nasality has come from research using synthetic speech, many studies have made use of spectrographic analysis to investigate features of nasality. However, the spectrographic analysis of nasality, it must be said, is not as efficient as many people believe it to be. As House (1957: 199) has pointed out, the system of filtering commonly used in spectrographic analysis does not allow a confident detection of pole and zero distribution in the spectrograms in the case of nasal sounds. Talking about spectrographic recordings, Fant says:

> "This does not mean that the [l] and [n] have a lesser number of formants than the vowels. Actually, they have more formants but there are not seen because of the limited range of intensity portrayal of the instrument" (Fant 1959: 16).

Spectrographic analysis of nasality is therefore very difficult. I have seen a tendency in every day practice to consider nasal formants as being 'pseudoformants' which appear in spectrograms of vowels as very faint intensity bars. Ladefoged (1975: 173) remarks that

> "These pseudoformants are sometimes due to a slight degree of nasalization. But often they are simply individual peculiarities. Their presence makes reading spectrograms more an art than a pure science";

and in the same book, he also calls the attention to the fact that

> "Spectrograms cannot be used to measure degrees of nasalization, nor are they much help in differentiating between adjacent places of articulation. For studying these aspects of speech, techniques such as X-ray cinematography are far more useful" (Ladefoged 1975: 187).

A more reliable way of investigating the formant-pattern of nasal sounds is to use a system of sweep frequency analysis. The subject must prolong the sound a bit longer than usual and during this period of time, for example, a 50 cps filter system performs an analysis from zero up to 4,000 cps. The readings are traced by a mingograph. The harmonic structure of the acoustic signal comes out very clearly and the formant envelope shape can be followed easily (Fant 1958: 53-55; 1959: 19-21; Fujimura and Lindqvist 1964: 1-7; Lindqvist and Sundberg 1976).

An alternative method of studying the pole and zero pairs can be performed by an inverse filtering technique. For further details see Fant (1961: 1-6) and Lindqvist (1963: 13; 1964: 1-4).

Mártony (1964: 28-31) carried out an investigation of formant amplitude variation of some nasals. He used the synthesizer OVE II with special control over the intensity and bandwidth of the formants. He found that a damping of formant one alone result in a 'kind of closed nasality', and that the most important cue for the perception of nasals, as far as intensity is concerned, is the low level of formant two (see Part V, Chapter 2).

Lindqvist and Sundberg (1976) took direct acoustic measurements of the transfer function of the nasal tract using a thin plastic tube as a probe inserted into the nose to pick up nasal resonances for analysis by a special experimental set-up for direct sweep tone measurements. The direct recordings of nasal resonances were compared with synthetic results, obtained from an analogue model of the vocal tract, based on data published by Bjuggren and Fant (1964). The direct measurements showed the relevance of the nasal sinuses as additional shunting cavities contributing to the complex pole-zero distribution in the spectrum of nasalized sounds, principally in the region of low frequencies (see Part V, Chapter 1, Section 1.5.).

1.6. Development of the Concept of Nasality

In ancient India, the grammarians described not only nasal consonants but also nasalized vowels, as having the airstream going out through the nose. The ancient Greeks, the Romans and the European grammarians until the 16th century described only the occurrence of nasal consonants represented by the letters m and n . At that time, few references were made to people who used to 'speak through the nose', as an individual feature of the speaker. During all this time, the velopharyngeal mechanism was but little understood.

By the end of the 17th century, we had a reasonably accurate description of the soft palate and of its importance in the production of nasal sounds. In von Kempelen's (1791) work, the soft palate and the process of nasalization were described in detail. He considered the nasals as sounds produced primarily by the 'voile du palais' (velum). According to him (von Kempelen 1791: 110-111), the velopharyngeal mechanism is put into action not only by the velum, but also by the faucal pillars, which he considered to be part of the velum. The velopharyngeal mechanism, then, changes the oral port continuously during speech. Velic closure is performed by a valvular action of the superior part of the 'voile du palais' closing the end of the nasal channel with an upwards movement (see Figures in between pages 108/109 and 112/113 in von Kempelen's work). He described four types of nasals: bilabial, alveolar, palatal and velar. He described the occurrence of a short homorganic nasal before stops, and said that a vowel followed by a nasal which is then followed by a consonant, is always nasalized. This nasalization is important in order to pronounce the nasal properly, without delay in the velic lowering, which could jeopardize the nasal quality of the nasal which needs the lowered velum for just a very brief moment (von Kempelen 1791: 325). He was probably the first to describe in full the articulation of (the French) nasalized vowels (von Kempelen 1791: 324-325). Von Kempelen (1791: 109) also reported that a person with a cleft palate produces defective speech.

Since then, phoneticians have been concerned primarily with the description of segmental nasality in languages. Very few and sometimes confused references were made to the occurrence of nasality over reasonably long stretches of speech, referred to as nasal twang. Studies of nasality as individual voice quality, typical of some speakers or group of speakers, are rare in the literature of phonetics. In this respect, Laver's (1975) work is of considerable importance. On the other hand, speech pathologists have been deeply concerned with the problem of nasality, when it occurs as a speech defect. They developed several theories of the production and causes of nasality, and have designed a variety of techniques and instrumentation to measure different degrees of nasality and to assess its occurrence as a speech defect. We shall review some of their techniques.

Gutzmann (1891) invented a procedure of clinical diagnosis of hypernasality based on auditory cues (see Part III, Chapter 4). Fritzell describes it as follows:

> "The patient is asked to produce a series of alternating [a] and [i] sounds. If a change in vowel quality is noted when his nostrils are pinched, this indicates an insufficient velopharyngeal closure" (Fritzell 1969: 9).

One of the first devices used to make a diagnosis of defective nasality and to help the speaker to control his nasalization, was the Pneumodeik. The Hudgins' Pneumodeik is a mechanical device similar to an old kymograph, but instead of a graph on smoked paper, a little red flag was attached to the end of the needle and moved up and down according to the amount of air leaving the nose. In this way, the speaker could better control the production of normal nasalization thus avoiding defective speech.

Another technique is Pronovost's open nasality indicator. The method is again similar to kymography, but the airflow is converted into an electric signal which is amplified and fed to a neon glow lamp. The relative amount of airflow produces relative brightness in the lamp, so that speakers could learn to control their nasalization by controlling the amount of airflow from the nose.

A third technique, and a recent one, is the Tonar, described by its inventor, S. Fletcher (1973), as a bioelectronic instrument. Tonar stands for 'The Oral-Nasal Acoustic Ratio'. The instrument was designed to solve some 'questions and implications concerning the apparently low reliability in judging perceived nasality' (Fletcher 1973: 139). Basically, the system is an improved version of the electrokymograph. It has an oral/nasal separator with two microphones to pick up sound pressure variations. The two readings are electronically compared and the ratio of the intensity of the two signals is computed. An oscillographic recorder displays the nasal, the oral and the oral/nasal intensity ratio as calibrated print-outs called tonagrams. The calibrated print-outs show how nasality varies with time acoustically. The instrument has been developed at the University of Alabama in Birmingham's Biocommunication Laboratory. A new version of Tonar incorporates a console unit which processes the ratio instantaneously and displays it as a digital output. A feed-back light panel is also used to give visual feed-back to the speaker, so that he can assess and control his own nasality.

Bernard et al. (1975) developed special instrumentation to measure nasality. It consists of a large, angled aluminium structure with a nose trumpet (Hyde 1968) at the angle where the subject places his nose. A microphone placed in the nose trumpet picks up the signal from the nose. Another microphone is placed on the aluminium structure, six inches below the subject's lips, to pick up the signal from the mouth. The oral/nasal sound pressure variations are compared with a given level of energy and all values which exceed the given reference level, called threshold zero, for more than 60 msec are stored in a computer. The computer gives the relative amplitude of the peaks and the oral:nasal ratio, i.e., the measure of nasality. The oral:nasal ratio is 'the area under the nasal curve divided by the area under the oral curve, multiplied by 100' (Bernard et al. 1975: 78). The authors pointed out that the oral:nasal ratio is useful procedure of assessing nasality objectively. When the ratio from different populations is established, it is possible to set up different degrees (ratios) of nasality.

These values would be very valuable in making a better diagnosis of hypernasality in relation to sociolinguistic values. Clarke (1975a) recorded the oral:nasal ratio from 65 males and 141 females, all normal speakers, using the technique described above. He found that the female population had a higher level of oral:nasal ratio (the mean being 32 - 35 %), and the male population had a lower level (the mean being 23 - 25 %); the lower value is that for spontaneous speech and the higher value for reading (Clarke 1975a: 55).

Another attempt to measure nasality has been reported by Serpa-Leitão and Galyas (1975). They used two contact microphones sensitive to acceleration, one placed on the neck at the right blade of the thyroid cartilage and the other on the right cartilageneous part of the ala nasa. Both pick-ups give DC signals of different polarities. In a timer integrator, the signals from the nose and the signal from the larynx are compared with a preset level thus producing a ratio in a numerical display. This ratio represents a 'percent nasal'. The technique is still at the stage of development and tests have not yet been conducted to establish the correlation between the acoustic nasal ratio of their recordings and auditorily judged degrees of nasality (see Part III, Chapter 4).

PART V : ACOUSTIC STUDY OF NASALITY

Chapter 1 : The Acoustics of Nasality

1.1. Introduction

The acoustic analysis of nasality is very difficult, although nasality can be detected by the ear relatively easily. What makes a sound be perceived as nasalized is a highly complex question from the acoustical point of view. Many researchers have carried out investigations to study the most prominent features of nasality and a review of the literature indicates that this area presents a great deal of variability. Experiments with synthetic speech compared with real speech analysis have revealed that the ear can recognize nasality when produced by a variety of different processes like special F-structure (formant-structure), specific resonances, at for instance, 250 cps or at 1,000 cps, damping, overal low intensity, presence of extra poles and zeros, etc. In real speech, nasality is usually accompanied by a surprisingly large number of such features, each of them being enough to give some 'nasal colour' to the basic sound. The origin of the modifications found in real speech spectrograms is not easily related to specific physiological gestures or anatomical configurations of the vocal tract, and often such modifications are created by synthesizers only after the introduction of special electronic effects which are completely arbitrary in relation to the vocal tract configuration.

The following works were the main contributers to the discussion of the acoustics of nasality that will now be presented: Paget (1924), Potter et al. (1947), Joos (1948), Liberman et al. (1954), Malécot (1956), House and Stevens (1956), House (1957), Fant (1960), Jassem (1962), Fujimura (1962), Hecker (1962), Delattre (1969a, 1969b), Fujimura and Lindqvist (1971), Lindqvist and Sundberg (1976).

1.2. Occurrence of Nasality in the Spectrum

Delattre (1969a, 1969b) investigated the occurrence of nasality in nasal consonants and nasalized vowels in a study combining spectrography and cineradiography. He came to the conclusion that the only feature common to nasal consonants and nasalized vowels is the lowering of the velum. Acoustically, nasal consonants and nasalized vowels manifest different features. When the acoustic structure of nasal consonants is compared with the acoustic structure of nasalized vowels, they present opposite characteristics. The F-1 (formant one) of nasal consonants is reinforced and the other formants are weakened. The F-1 of nasalized vowels is weakened and the other formants are reinforced. The (French) vowels have a fixed F-1 at about 500 cps, because of the volume of the pharyngeal cavity being adjusted to equal the volume of the nasopharynx. The nasals have a fixed F-1 at about 250 cps, due to a large pharyngeal cavity. Different nasalized vowels are differentiated by the location of F-2 and F-3. The nasal consonants are differentiated by the transitions of neighbouring vowels. Briefly, one could say that, according to Delattre, the nasals are characterized in general by two cues: the F-pattern (formant-pattern) or nasal resonance (or 'nasal murmur') which gives the audible nasal quality to the sound, and the transitions, which mark the differentiation of the various places of articulation of the nasal consonants. The nasalized vowels are characterized by a weakened F-1, that can be equalized for all (French) nasalized vowels at approximate 500 cps, representing the ideal nasalization, i.e., when the pharynx cavity is adjusted to the same volume as the nasopharynx.

Fant's (1960) acoustic analysis of nasality considers that nasalized sounds produced with complete oral obstruction (nasal consonants) or with a free pathway in the mouth for the airstream (nasalized vowels), can be regarded acoustically as a process of interaction of cavities. However, in terms of classification, Fant suggests that three types of articulation can be set up, because of their peculiar influence on the spectrum.

The first type occurs when the velum shuts off access to the nasal cavities and the airstream escapes only from the mouth, as in oral sounds. In this case, there is no nasality present. The second type occurs when the velum is lowered, with the inlet to the nasal cavity open and the back of the tongue forming a complete obstruction with the lowered velum, so that the airstream is driven completely into the nasal cavity. In this case, there is no formation of any sort of oral cavity. This happens with velar and uvular nasals. The third type is characterized by a lowered position of the velum, but without a complete seal between the back of the tongue and the velum, so that the oral cavity is connected to the nasal and pharyngeal cavities. The oral cavity can be blocked at some point by a complete obstruction to the airstream, made by the tongue against the palate, or by the lips, as in the case of bilabial, alveolar, palatal nasals, etc., or it can be open, as in the case of nasalized vowels.

A nasal consonant has distinct acoustic effects which relate to the complete obstruction in the mouth, leaving just one outlet for the sound from the nostrils, while a nasalized vowel has two outlets, one from the nostrils and one from the mouth. Therefore, acoustically, the distinction between nasals and nasalized vowels is quite clear. Acoustically, a nasal consonant has its own characteristics, while a nasalized vowel is, in fact, characterized by the way the spectrum of the corresponding oral sound is modified when nasalization is added to it. Nasalization, rather than nasal resonance, is characterized by superimposition of the features generated by the coupling of the nasal cavity upon the basic structure of the oral counterpart. A nasal is not a stop plus nasality when a detailed acoustic analysis is carried out, but it has individual characteristics.

The study of nasalization is much more complex than the study of nasal resonance, since nasalization is a process of superimposition, depending crucially on the type of sound upon which the process of nasalization will act. Another common difficulty in the acoustics of nasality is the variation from person to person in anatomy and in the state of the nasal cavities, since this causes variation in the final output when nasality occurs. The configuration of the nasal and oral ports is also highly variable and is one of the most important factors in the characterization of nasality in speech. Fant (1960; see also Bjuggren and Fant 1964) conducted a comprehensive anatomical and acoustic study of the nasal cavities and found it difficult to measure the nasal cavity and to set fixed resonatory values for it. Van den Berg (1962: 117) pointed out that nasality is characterized acoustically by severe damping, and severe damping can be caused not only when the nasal cavity is integrated with the oral tract, but it may also be produced in the oral tract without the participation of the nasal cavities (see Part III, Chapter 2, Sections 2.3. and 2.4.). He carried out experiments using an analogue speech synthesizer producing a large amount of damping in the pharynx; the result showed that an oral sound becomes nasalized under these conditions.

Nasality is commonly achieved in synthetic speech by adding a nasal resonance at 250 cps (or at 1,000 cps), by weakening the amplitude of F-1 of a sound, by an overall decrease in intensity, by introducing special antiresonances at specific levels, or by generating a specific F-pattern with resonances at, for example, 200, 1,200 and 2,400 cps. We will discuss some acoustic properties of nasality in more detail now.

1.3. The Acoustic Properties of the Nasal Cavity

Some investigators have observed that the nasal cavities have only a damping effect on sound. Delattre says:

> "There are reasons to believe that this velar (sic) cavity (nasopharynx) alone has walls firm enough for efficient resonance; the other nasal cavities, those which terminate in the nostrils, have fibrous walls and could only have a damping effect" (Delattre 1969a: 95).

Kaplan, on the other hand, states:

> "The nasal cavities are subdivided into many variable sized air spaces, and they should not be considered as a pair of large nasal chambers. The subdivisions of the nose tend to clarify it as a multiple resonator" (Kaplan 1960: 215).

In the production of nasalized sounds, the nasal cavities can be regarded as a side chamber cavity. In the production of nasal consonants, the side branch cavity will be the oral cavity, and the nasal cavities associated with the pharynx will form the principal resonator tube of the vocal tract. See House and Stevens (1956) and Hecker (1962: 183). A side branch resonator modifies the output, i.e., the typical distribution of poles and zeros, by introducing new zeros (antiresonances) wherever its input impedance is zero. When the nasal cavities function as a side chamber resonator, they are responsible for a general damping in the spectrum (principally of F-1), a broadening of the bandwidth of the formants, and other secondary effects upon the envelopes of the sound over which the effect of the side branch resonator is superimposed.

Working with a nasal analogue synthesizer, House (1957: 202) found that, with maximal coupling, nasal cavity resonances occurred at 400 cps and 2,500 cps. Bjuggren and Fant (1964: 6) working with a model of a real (female) nasal cavity, found that the nasal cavity bounded by the nostrils and posterior nares has a natural frequency of approximately 1,000 cps, and, with the nasopharynx included and the nasal port closed, of approximately 500 cps. They comment:

> "These figures, however, might perhaps be somewhat lower, due to additional mass elements at bends and at the internal orifice related to radiation terms of the wave equation. The anatomical variation of nasal cavity dimensions is appreciable and it is highly probable that thin-nosed individuals would have even lower natural frequencies of the nasal cavity system than indicated above. A physiological requirement for the base formant of a nasalized vowel to be low in frequency and fairly independent of the speakers F-1 is that the fundamental resonance of the nasal system is indeed low" (Bjuggren and Fant 1964: 6-7).

The spectrum can be influenced by obstruction in the nasal cavities as well, as happens when one has a cold. The presence of mucus in the nasal cavities and the differences in the nasal cavity anatomy from person to person are responsible for variations in the spectrum. Another anatomical factor which produces variations in the spectrum occurs when the left and the right channels are not symmetrical. When both channels are symmetrical, they can be regarded as a single cavity system acoustically. When they are assymmetric, they generate extra poles and zeros in the mixing of the outputs from the nostrils, adding additional diffusion of spectral energy (Fant 1960; Fujimura 1962). The rise in frequency of the zero is directly proportional to the assymmetry of the nasal channels (Fujimura 1962).

House and Stevens (1956: 225) using an analogue synthesizer, investigated the effect of reducing the nasal damping in nasalized vowels and found that it causes additional poles to appear above F-1, around 1,000 cps, and an antiresonance in the range of 700-1,800 cps depending on the amount of nasal coupling.

1.4. The Acoustic Properties of the Nostrils

Catford (1977) includes a 'nareal articulation' in his articulatory system. This articulation is performed by the nostrils and can produce an approximant or a fricative sound. He says:

> "Nareal articulation is produced at the nostrils, or nares. If you produce a long [m::] sound, then, while keeping a powerful pulmonic egressive air-stream going, devoice it, you will produce 'voiceless m' [m̥] . Now, at any but a very low volume-velocity it will be evident that [m̥] is characterized by turbulent flow through the nostrils - nareal turbulence. The nasal [m] then, is produced with no turbulence when voiced, but with nareal turbulence when voiceless; it could thus be correctly described as a nareal approximant. A further narrowing of the nostrils will convert a nareal approximant into a nareal fricative. Experiment by setting up the articulation for [m] , and starting up a pulmonic egressive voiceless air-stream. Notice the hiss generated by turbulent flow through the nostrils. Now, while this sound is going on, contract the nostrils so as to make the nareal channel narrower. Immediately the intensity of the hiss increases. Now add voice, keeping the hiss of turbulence going at the same

time. This is a voiced nareal fricative, which we may represent as [m⊥] " (Catford 1977: 138-139).

Fant (1960) conducted some experiments to investigate the influence of different types of nasal outlets upon the characterization of nasality. He found that with a narrow nasal outlet, there was a zero at about 700 cps, but with a wider nasal outlet, the zero shifted to 900 cps. With the nostrils completely closed, that zero dropped to 500 cps. In the latter case, there was also a nasal pole at 300 cps, a raised F-1, F-4 fused with F-3, and a second nasal pole.

I conducted an experiment to investigate the effect of adding different types of nasality to the basic spectrum of an oral vowel. An oral vowel [ε] was nasalized, and the production of the resulting nasalized vowel was sustained while the nostrils were pinched with two fingers. The results support Fant's findings.

In this experiment, a spectrogram was made of an uninterrupted pronunciation starting with the vowel [ε] that becomes [ε̃] by lowering of the velum, and is later modified by pinching the nose. Three spectrographic sections were done centered at the three moments of the spectrum related to the three articulations described above. Fig. 14 gives the spectrum envelope of each of them, together with the three envelopes superimposed for comparison. The estimated values of the most prominent peaks and zeros are given in Table 1 . In Table 1 , two numbers separated by a horizontal bar represent the estimated value of the bandwidth of the antiresonance, that is, the beginning and the end of the antiresonance band.

The fact of pinching the nose produces a very noticeable modification in the spectrum, by enlarging the bandwidth of the antiresonances, and causing a split effect on formant one and

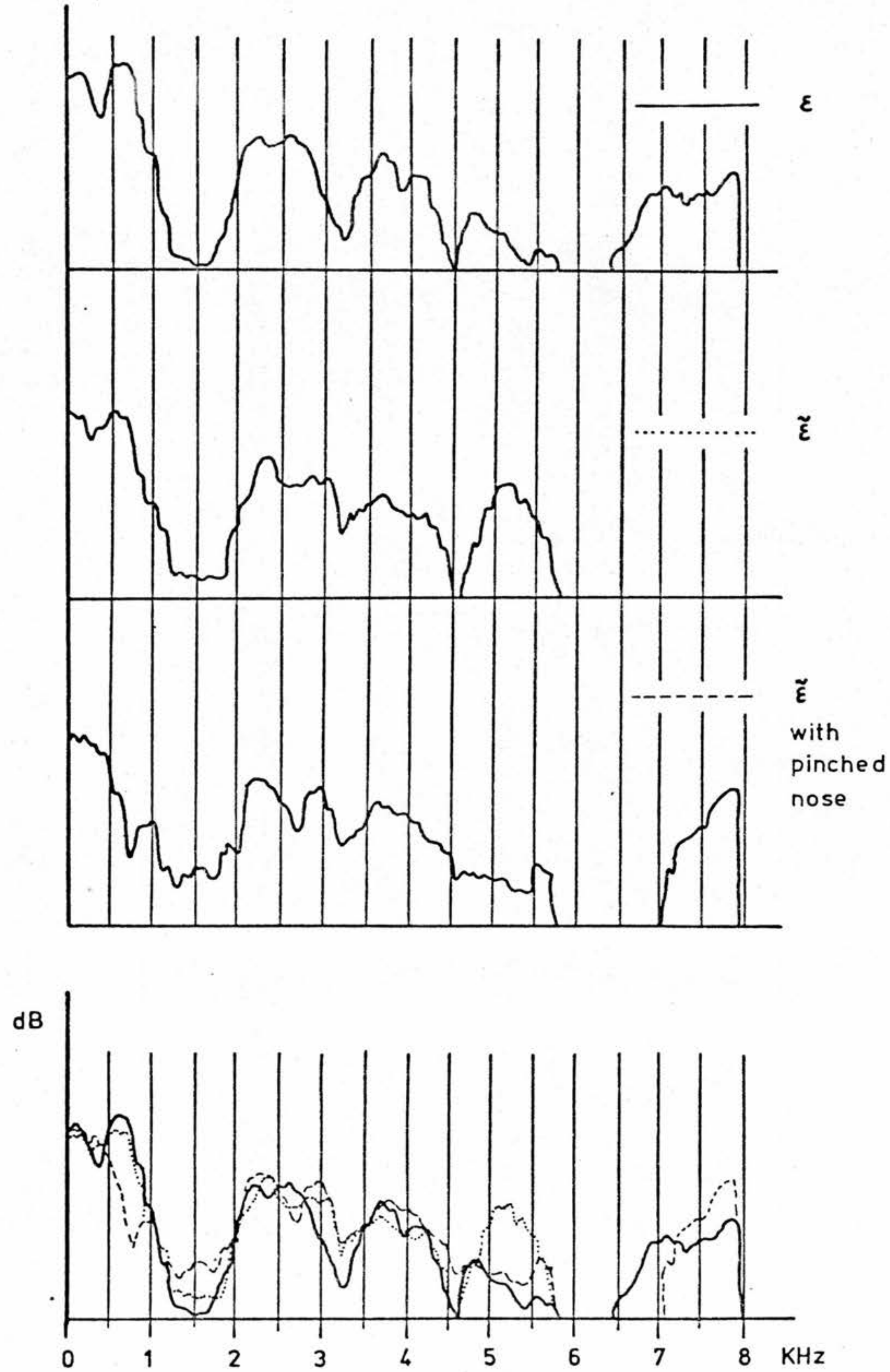


Fig. 14 Spectrographic sections of a vowel uttered orally, nasalized, and nasalized with the nose pinched closed by two fingers. The bottom diagram contains the three acoustic envelopes presented above, superimposed for comparison.

VOWELS	ε	ε̃	ε̃ with pinched nose
POLES	600	500	250
			1,000
	2,300	2,250	2,100
	3,750	3,750	3,750
	4,750	5,250	5,500
ZEROS	350		750
	1,250	1,200	1,100
	———	———	———
	1,700	1,800	2,100
		2,700	2,700
	3,250	3,250	3,250
	4,500	4,500	4,500

Table 1 Pole and zero values of the same vowel uttered orally, nasalized and nasalized with the nose pinched closed by two fingers. Two numbers separated by a horizontal bar, represent the estimated values of the bandwidth of the antiresonance.

formant two. On the other hand, the zero with the bandwidth around 1,200 cps to 1,800 cps, present in the case of [ɛ] and [ɛ̃] is not present when the nose is pinched. The spectrum of [ɛ̃] reveals that simple nasalization tends to affect the spectrum by flattening the peaks. Although the spectrum of [ɛ̃] with pinched nose, has very noticeable antiresonances as an individual feature, in comparison with the other two spectra, the effect of pinching the nose tends to produce a more effective flattening of the peaks than the simple nasalization. The effect of simple nasalization of the vowel tends to increase certain high frequencies. In this particular case, this increase is clear around 4,600 - 5,800 cps. The pinching of the nose reduced this band of frequency very much. The oral vowel revealed an antiresonance with a narrow bandwith ranging from 5,750 cps up to 6,500 cps. In the case of [ɛ̃] the cut-off occurred around 5,750 cps and no acoustic energy was registered beyond that point. The reason for this is not clear. In the case of the nasalized vowel [ɛ̃] with the nose pinched, the zero has a very wide bandwidth ranging from around 5,750 cps up to 7,050 cps, and then there is some acoustic energy up to 8,000 cps. The acoustic energy at this high frequency area is more intense for the vowel with the nose pinched than for the oral vowel.

1.5. <u>The Acoustic Properties of the Sinuses</u>

The idea that the sinuses play no role at all in the production of speech is fairly widespread (Curry 1940; Tarneaud 1941; Hahn et al. 1952; Negus 1957; van Riper and Irwin 1958: 245; Greene 1964: 69; Zemlin 1968: 252). The reason is usually stated in terms of the fact that the opening of the ducts connecting the sinuses to the nasal cavities is too small. Kaplan comments:

> "Greene differentiates the relative importance of the sinuses as resonators. The maxillary sinuses are stated to be important because they are large and open into the nose by fairly large orifices. The other sinuses, and also the eustachian tubes and mastoid air cells, are small, closed in, and waterlogged. Since they have inadequate communication with the external air, their resonating function is problematical" (Kaplan 1960: 225).

Kaplan in fact adopts a compromise position in this case, saying that

> "The paranasal sinuses, which are diverticula, or recesses, of the main nasal cavities, have been said to contribute to general resonance, although their influence is ordinarily slight or even doubtful. The sinus contribution is relatively fixed and perhaps may be thought of as a part of the nasal resonance component of speech. The bones of the skull surrounding the air sinuses are fairly thin and may add a forced vibration to the tone" (Kaplan 1960: 215-216).

The role played by the sinuses in speech has been investigated recently with some interesting results which indicate better matching of synthetic spectra with spectra from real speech.

In a recent work, Lindqvist and Sundberg (1976) discussed the problem of the acoustic envelope of nasalized vowels and nasal consonants saying that it is difficult to explain the presence of numerous poles and zeros of the nasalized vowels occurring below 1,000 cps by means of the traditional analogue model alone with a symmetric or an ansymmetric nasal tract. These poles and zeros are not explained by the mouth cavity resonances alone, but they indicate the existence of other shunting cavities. These other shunting cavities are probably the maxillary sinuses, the frontal sinuses and perhaps other small cavities.

Lindqvist and Sundberg (1976) treat the acoustic properties of the sinuses as if they were Helmholtz resonators coupled to the nasal cavities. In their measurements, the resonance range of the maxillary sinus varies within approximately 200 - 800 cps and the frontal sinus varies within 500 - 2,00 cps. Their new analogue model, with symmetrical sinuses generates only one extra pole-zero pair. With assymmetrical sinuses, more pole-zero pairs can be expected (see Part IV, Chapter 1, Section 1.5.). They say:

> "The acoustic system is also quite complex because zeros are caused not only by shunting cavities but also by asymmetry and mixing of the outputs from the two nostrils. Nevertheless, a quite good match of the response curves could be obtained with only two shunting cavities. If the sinuses do behave as Helmholtz resonators, they will have only one resonance each in the frequency range studied" (Lindqvist and Sundberg 1976: 166).

With this new analogue model, the synthetic spectrum involving nasality can match more efficiently the spectrum of nasal consonants and nasalized vowels of real speech.

Nord (1976b) included an extra pole-zero pair in series with the vowel branch of OVE III to see whether the additional pole-zero pair would improve the quality of synthetic nasal consonants. The pole-zero distribution was investigated, using an analysis-by-synthesis technique, with a procedure of matching the nasal resonance envelope with the nasal envelopes from real speech. Listening tests proved that the addition of the extra pole-zero pair improved the quality of the nasals. This means that additional side branches have a positive effect upon the quality of the nasal resonance.

1.6. The Acoustic Properties of the Oral Cavity in the Production of Nasality

The oral cavity plays no part at all in the production of uvular nasals and, in practice, it can be considered irrelevant in the production of velar nasals (Fant 1960). However, in the production of other possible nasal consonants, the oral cavity acts as a side branch resonator. In this case, the main tube is formed up by the pharyngeal and nasal cavities. With the coupling of the mouth cavity to the nasal and pharyngeal cavities during the production of a nasal consonant (except velar and uvular nasals), there is an increase in the total cavity volume with a corresponding lowering of the frequency of F-1. The degree of lowering of the velum and the position of the tongue higher or lower in the mouth, modify the oral cavity configuration, so that the antiresonance can shift up to 1,000 cps and cause the neutralization of the nasal formant that occupies that position (Fant 1960). On the other hand, in the production of a nasalized vowel (or any nasalized continuant sound), the oral cavity together with the pharyngeal cavity constitute the main resonator chamber and the nasal cavity has the effect of a side branch resonator (see Section 1.2. of the present chapter).

The most important acoustic effect of adding a side branch is to cause a shift in some frequency areas, and the introduction of antiresonances. The different points of articulation of the nasals creating side chambers with different volumes, cause a directly related variation in the shift of some frequencies and in the location of the antiresonances in the final spectrum.

Fujimura (1962) points out that the shifts that occur in the formants and antiformants of the nasal consonants along the time axis, are due to the continuous movements of the tongue. The effect of the articulatory movements upon the frequency energy distribution is crucial at segmental transitions in giving the major perceptual cues for differentiating the nasals (see Section 1.2. of the present chapter).

1.7. The Acoustic Effects of Coupling the Nasal Cavity with the Oral Tract

In the case of nasal consonants, the coupling of the nasal cavity with the oral tract completely modifies the configuration and properties of the vocal tract. The combined nasal and pharyngeal cavities form the main tube and the oral cavity a side branch. This new set-up in the vocal tract gives rise to the special F-pattern of the nasal consonants, with the pole and zero distribution varying according to the changes that take place in the mouth for different types of nasal consonants. Because of the acoustic properties of the nasal tract, nasal consonants will have some bands of frequency in the low frequency area, reinforced, with a great reduction in the intensity of the high frequency areas, due to the damping effect caused by the nasal tract and the antiresonances produced in the oral cavity.

The effect of coupling the nasal cavity to the oral tract in the production of nasalized sounds has been investigated in synthetic speech with analogue models of the vocal tract. Fant (1960) studies the nasalization of vowels with the electrical line analogue LEA, comparing the hypothetical data with real speech. Acoustically, the nasalization is characterized by being a pole-and-zero pairs phenomenon which occurs in determined areas of the spectrum causing the spectrum to be modified. The most important modification is the reduction that occurs in F-1, due either to the presence of antiresonances nearby or to an increase in the formant bandwidth that occurs when nasalization is added to the spectrum of an oral sound (see Section 1.2. of the present chapter).

F-1 also varies in its frequency range according to the coupling area, that is, according to the degree of lowering of the velum. A bigger area causes a rise in the frequency range of F-1; conversely, a smaller area causes a lowering in the frequency range of F-1. Thus, one can say that the lowering of the velum is directly proportional to the shift up of F-1. Such shift of F-1 when an oral sound is nasalized can cause it to have a change in its perceived quality. Fant (1960) said that, in these circumstances, an [i] can sound auditorily like an [ĩ] or an [a] like a shwa. This point will be discussed later (see Part V, Chapter 4, Section 4.1.).

House and Stevens (1956), using an electrical analogue in a study of the effect of nasalization upon vowels, produced very interesting results. The coupling was electronically variable and the resulting synthetic speech was analysed auditorily. The effect of the variations upon the original spectrum of the vowel was also investigated. The acoustic effect of coupling was found to influence F-1 most of all. As a consequence of the coupling of the nasal cavity, the F-1 showed a tendency to be higher in frequency (Björk 1961: 399 reported opposite findings in his study), higher in bandwidth and lower in intensity. A new formant appeared near 1,000 cps and new peaks appeared in different places in regions of higher frequencies. The high formants presented differences and irregularities which were less systematizable. The higher formants also have a reduction in intensity which is less than the reduction typical of nasal consonants. An increase in the coupling area showed a tendency to flatten and broaden the peaks, with further changes in the characteristics of F-1. F-3 tends to be eliminated more easily than F-2 and additional poles (resonances) were introduced. The zero (antiresonance) that occurred within the range of 700 - 1,800 cps was susceptible to variations of coupling. Different degrees of coupling moved this antiresonance within the given range of frequency (see Part III, Chapter 5).

Auditory tests showed that with an increasing area of coupling, the vowels [i] and [u] were perceived as nasalized vowels sooner than [ɛ] or [ɔ]. The last vowel to be heard as nasalized was [a] (House and Stevens 1956: 229-230). They also presented an [æ] without nasal coupling but with very large bandwidth, and the listeners perceived as a nasalized vowel. In the case of nasals, nasal resonance is perceived more readily when there is an increase in coupling (see the suggested neutral velic scale in Part III, Chapter 5). A very small coupling produces a sound which is recognized as a vowel rather than as a nasal consonant, according to synthesis experiments done by House (1957). The spectrum has low frequency energy around 200 - 300 cps, an acoustic energy prominence near 1,000 cps and a zero that varies according to the location of the closure in the mouth. The frequency of the higher formants is drastically reduced and in general the spectrum presents an overall low level of acoustic energy distribution.

Delattre (1969a, 1969b), using synthetic manipulation of speech, demonstrated that the movements of F-3 which were believed to relate to the lowering of the velum (Hockett 1955: 203), have no effect upon nasal resonance at all.

In all published experiments using synthetic speech, there is no reference to the production of a velic fricative, cause by a special degree of narrowing at the nasal port. Catford, however, says:

> "It is possible to narrow the velic orifice to a greater or lesser degree, producing velic fricative and approximant

articulations" (Catford 1977: 139).

Variations in the degree of nasal coupling and nasal port configuration are beleived to be related to different degrees of nasalization. However, there is no mention of this sort of variation in works investigating the effects of nasal coupling with analogue synthesizers. But, Fant (1960) made some comments on the subjective evaluation of degrees of nasalization saying that a synthesized vowel is perceived with a greater or lesser degree of nasalization according to the amount of pitch variation. He observed also that by adding a vibrato phonation to a nasalized sound the effect is to neutralize the presence of nasality.

Finally, there is one more consideration to be made relating to the discrepancy between whether or not the coupling area is completely closed, and the perception of audible nasality. We have seen that there is a functional closure and a velic scale which effectively controls how large the coupling area must be to produce required speech segments. Karabinos (1973) suggests that this functional closure must be controlled by a voluntary action by the speakers in order to keep the utterances in accordance with the general and acceptible phonetic requirements on different occasions. She says:

> "The significant voluntary control of the velar swing and elevation is apparent in subject CE 100 % of the time; it supports Lübker (1968) that the speaker allows the velum to be in a low or mid position during production of a vowel because it will not be perceived as nasal by the listener. This reflects a phonetic competence by the speaker, as proposed by Tatham. Specifically it is an example of an intrinsic tendency counteracted by the speaker, motivated by perceptual criteria" (Karabinos 1973: 32).

Chapter 2 : The Acoustics of Nasal Consonants

In his analysis of the acoustical structure of nasal consonants, Delattre (1969a, 1969b) found that, contrary to the vowels, the nasal consonants have a stronger F-1 than other formants, as we reported earlier. Articulatorily, they have a pharyngeal cavity similar to the formation of a high vowel, i.e., a large pharyngeal cavity. The other formants, that contribute to nasal resonance, are weaker in intensity, are similar in all nasal consonants, and have no important role in distinguishing the place of articulation of nasal consonants. Delattre comments:

> "The first formant of the nasal murmur has a frequency of about 250 cps and is complemented by an indefinite number of higher formants of very low intensity and of irrelevant frequency as far as distinguishing one place of articulation from another. All this has been confirmed by the manipulation of synthetic speech. (The frequency of 250 cps is fairly critical - when it is changed to 350 or 400 cps, [ma] changes to [la])" (Delattre 1969a: 97).

Joos (1948), in an earlier investigation of the F-pattern of the nasal consonants, came to the conclusion that the nasal formant that appears around 1,000 cps could be regarded as a fixed resonance which gives the nasal colour to nasal consonants. He considers this resonance to be caused by the lowering of the velum, and to be the most important cue in the perception of nasality in general. Although this resonance plays a very important role in nasalized vowels, it appears to be less important in the case of nasal consonants, the resonance around 250 cps being by far the more important.

The resonances that appear in the spectrum of nasal consonants are created by the combined pharyngeal and nasal cavities. Some researchers (Potter et al. 1947; Liberman et al. 1954; Malécot 1956;

Delattre 1969a, 1969b) found that the F-structure is the same for all nasal consonants, or at least it could be the same in synthetic speech, the differentiation being performed by different transitional patterns. However, other researchers pointed out that nasal consonants are differentiated with different places of articulation by having specific F-patterns (Fujimura 1962; Jassem 1962). Furthermore, Fujimura (1962) observed that if one looks at the spectrum of bilabial and alveolar nasals, it will probably be difficult to distinguish them by the general configuration alone, but when a detailed analysis is carried out, the F-structure and antiresonances are detected, the nasal consonants will appear to be very different from one another. Discussing the nasal consonants, Jassem says:

> "They have a distinct formant structure. Below 4 kHz up to seven formants can be distinguished. All nasals have one formant near the first harmonic, two around 2 kHz and two (or sometimes one) just above 3 kHz" (Jassem 1962: 125-126).

He also found that the nasals [m, n, ɲ, ŋ] are differentiated by the different energy distribution that occurs in the range between 300 cps and 1,800 cps (Jassem 1962: 126).

The higher frequencies are commonly considerably weakened in nasal consonants. Potter et al. (1947) made an interesting observation about the relationship between different levels of stress and the F-structure of nasal consonants:

> "The number, darkness and resolution of the bars depends upon the degree of stressing and upon the relative proportions of closed and open cavity modulation. An unstressed nasal may be portrayed by a voice bar alone, while an overstressed nasal may produce a vertical pattern of overlaid bars which have a diffuse or smeared appearance" (Potter et al. 1947: 166).

As we said earlier, the presence of antiresonances and zeros in the spectrum of nasal consonants depends primarily on the oral articulation shaping different side chambers in the mouth, behind the occlusion made by the tongue (House 1957: 198).

Because of the damping effect caused by a large surface area in the nasal cavity, the nasals have large bandwidths and a decrease in overall amplitude compared, for instance, with other resonant sounds, as already mentioned earlier.

Some data related to the distribution of poles and zeros of some nasals will be presented next. House (1957: 198-199) gave the following specifications for the F-pattern of nasal consonants:

F - 1	:	200 - 300 cps		
F - 2	:	1,000 cps		
Antiresonances	:	[m]	:	around 1,000 cps
		[n]	:	around 3,500 cps
		[ŋ]	:	above 5,000 cps

Paget (1924) gave the following resonances for nasal consonants:

200 cps	1,300 cps
600 cps	2,400 cps

House (1957: 198) reported that in the Pattern Playback, the following formants were used to produce synthetic nasals:

F - 1	:	200 cps
F - 2	:	1,200 cps
F - 3	:	2,400 cps

Liberman et al. (1954: 326) used the following F-pattern to produce synthetic nasals:

F - 1	:	240 cps
F - 2	:	1,020 cps
F - 3	:	2,460 cps

Hecker (1962: 184) investigated the location of poles and zeros, using a special analogue synthesizer, and found a similar distribution of poles for the bilabial, alveolar and velar nasals within the frequency range given below (the lower figures being more typical of the bilabial nasal, and the higher figures, more typical of the velar nasal) :

F - 1	:	200	-	300	cps
F - 2	:	800	-	1,500	cps
F - 3	:	2,000	-	3,000	cps

However, he observed that the nasal consonants can be differentiated by the location of the first zero; his data are as follows:

zeros	:	[m]	between	800 - 1,500 cps
		[n]	between	2,000 - 3,000 cps
		[ŋ]	above	3,000 cps

And Hecker concludes:

> "Consequently, the location of the first zero may be an important factor which distinguishes the nasal consonants from one another" (Hecker 1962: 184).

Jassem (1962: 126) reported the following distribution of poles in the spectrum of nasal consonants up to 2,000 cps :

[m]	:	700	1,200	(strong resonance)
		400 cps		(faint resonance)
[n̪]	:	700 cps		(weak resonance)
		1,500 cps		
[ɲ, ŋ]	:	800 cps		

but, just above 2,000 cps, the palatal nasal has two formants close together, while the velar nasal shows a different pattern. For the bilabial nasal, he reported a formant around 1,000 cps, which varied according to the neighbouring vowel.

Although Fant (1960: 147) found specific values for the F-pattern of different nasal consonants, he came to the conclusion that the structure of the nasal murmur could be said to have resonances close to the following areas in the spectrum for all nasals:

250	cps	(with a dominating intensity level)
1,000	cps	(very weak indeed)
2,000	cps	(with expected shifts when the nasal is coarticulated with back vowels)
3,000	cps	
4,000	cps	

So, F-1 has a high intensity level and F-2 a very weak intensity level. Sometimes, F-2 will be absent from the spectrum. Fant attributed the resonance near 1,000 cps to the nasal cavity, and the antiresonance effect of the coupling of the mouth cavity to the nasal cavity is characterized by the following calculations:

zeros:	[m]	:	550	3,500	cps
	[ɱ]	:	1,800	5,600	cps
	[n]	:	1,800	5,600	cps
	[ŋ]	:	2,200	6,400	cps

The frequencies above indicate the area where the pole-zero pairs occur in these sounds. Fant continues

> "There are also formants that depend on the oral cavities, but they are severely weakened owing to the fairly close proximity of zeros" (Fant 1960: 147).

Fant (1960: 142-145) made measurements with the electrical line analogue LEA for a hypothetical synthesized velar nasal, whose results are given below:

F - 1	:	300 cps	(due to pharynx plus nasal systems)
F - 2	:	1,000 cps	(due to nasopharynx resonance)

F - 3	:	2,200 cps	('half-wave length resonance of the pharynx cavity')
F - 4	:	2,900 cps	('second impedance minimum of the nasal system above the uvula')

He observed that these data indicate that the velar nasal has a F-structure similar to the spectrum of [u] , one clear difference being the large damping of F-2 and higher formants in the nasal.

Fujimura (1962) carried out an investigation of bilabial, alveolar and velar nasals with an analysis-by-synthesis technique (see Part IV, Chapter 1, Section 1.5). The distribution of poles and zeros were read at successive 8.2 msec intervals along the time axis in order to see the variation in the distribution of energy during the nasals. He described nasal resonance as a formant-antiformant structure. The frequencies of the antiformant represent 'the selective absorption of the outcoming sound energy due to the openfield (short circuit) resonance of the oral tract' (Fujimura 1962: 2). The distribution of the antiformants is different for each nasal, so that the nasal consonants can be differentiated by them. He says:

> "...the antiformant is the feature that distinguishes the three nasals within the class. In the frequency range up to about 2,000 cps or slightly higher, the nasal murmur of the bilabial and postdental consonants have four formants and one antiformant. The antiformant of [m] generally lies very close to the second formant, which is located around 1,000 cps or slightly lower. The antiformant for [n], on the other hand, is close to the third formant, which is around 1,500 cps, or sometimes well above it, but not higher than the fourth formant" (Fujimura 1963: 3).

For the velar nasal, the antiformant has been found above 2,000 cps, and therefore, above F-3. This nasal has its three first formants regularly distributed with a range of 800 cps between them, F-1 being at 300 cps.

Fujimura (1962) used another name for the formant-antiformant structure: the formant-antiformant cluster. For the bilabial nasal, the formant-antiformant cluster consists of F-2 plus antiformant plus F-3, which appear relatively close to each other in the spectrum. For the alveolar nasal, we have F-3 plus antiformant plus F-4, which appear less concentrated in the spectrum. The formant- antiformant cluster of the bilabial nasal occurs approximately in the same region as F-2 of the velar nasal, but the difference is that the formant is of regular type, while the formant-antiformant cluster introduces irregularities in the acoustic envelope where it appears, and is very sensitive to movements of the tongue. About the general characterization of the nasal consonants, he says:

> "In the central frequency range of the spectrum of the nasal, therefore, there are no high peaks or marked valleys such as occur in the vowel spectra. The higher value of formant bandwidth and the higher density of formants also are responsible for this characterization of the nasal spectra. These spectra characteristics can be found also in [m] or [n] , since the local fine structure of the cluster usually cannot contain a sharp peak or wide and deep valley. Thus, the boosted low components and suppressed and less concentrated components in the middle (to high) frequency range constitute the common gross feature of all nasal spectra. It may be said, therefore, that all nasal consonants, as far as the murmur is concerned, sound grossly alike" (Fujimura 1963: 4-5).

Fujimura (1962) reported the following F-structure from real speech nasals:

nasals:	bilabial	alveolar	velar
poles :	280	300	350 cps
	940	1,050	1,050
	1,240	1,450	1,900
	1,950	2,000	2,750
	2,560	2,650	
		3,300	
		3,600	
zeros :	980	1,600	above 3,000 cps

In Nord (1976a: 16-17), the distribution of the poles for the bilabial and dental nasal is similar to Fujimura's findings, and the difference between the two nasals is characterized by the different location of the second and third zeros: the zeros of the dental nasal have higher frequency locations in the spectrum.

I have carried out some investigations on the F-structure of seven different nasals to compare their differences and similarities. The results agree in general with the data from other investigators reported above.

In the literature, we regularly find studies dealing with bilabial, alveolar and velar nasals, the three nasal consonants of English. There is practically nothing published about other nasals. So, I decided to investigate the spectrum of a number of other nasals. All the selected nasals were uttered by myself and they occurred between the vowels [a] and [ɜ]. In Fig. 15, the spectral envelopes of six types of nasals investigated (i.e., [n̪, ɳ, n, ɲ, ŋ, ɴ]) are shown. In Fig. 16, the spectral envelopes of the six nasals above are superimposed for comparison; and in Fig. 17, the spectral envelopes of [m] and [ɲ] are compared. Table 2 presents estimated values of the most prominent poles of the spectra, together with an assumed location of the antiresonances or zeros.

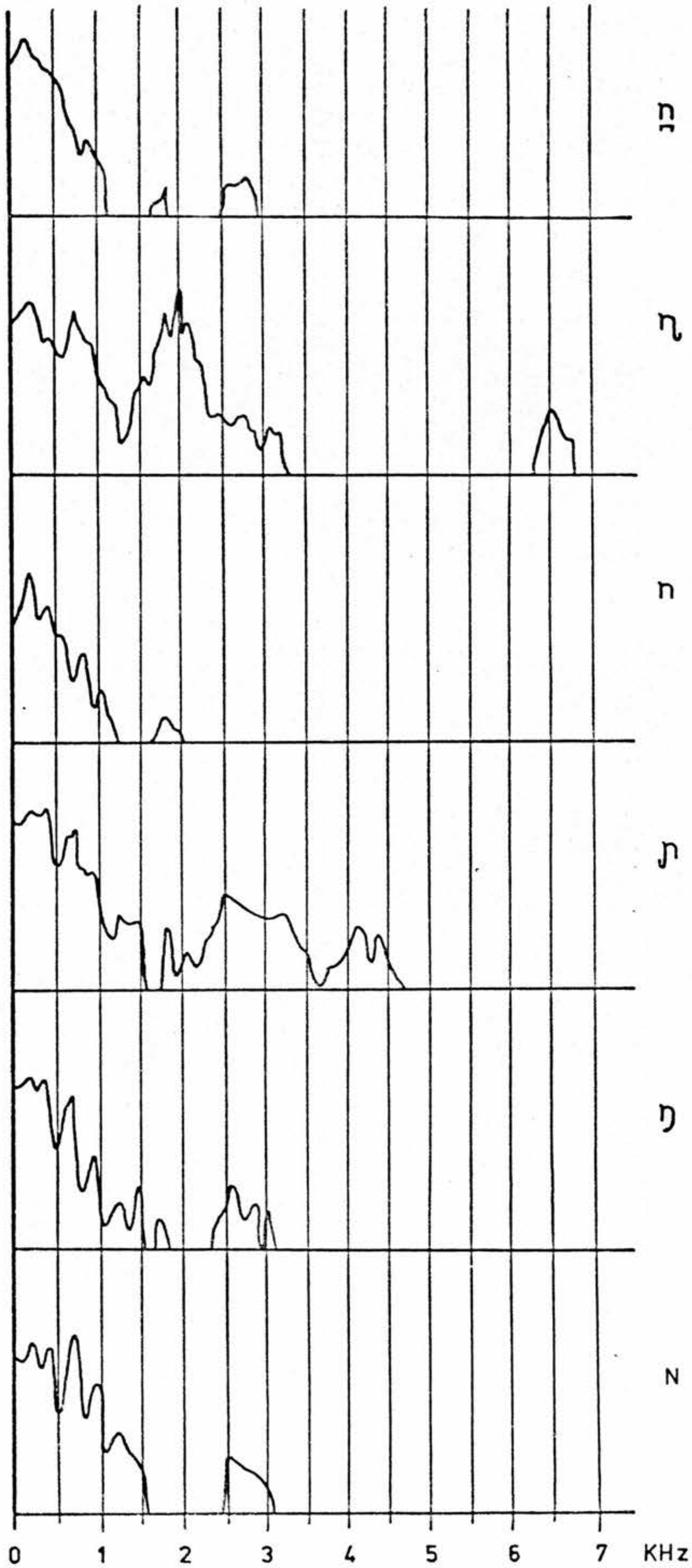


Fig. 15 Spectrographic sections of six different types of nasals.

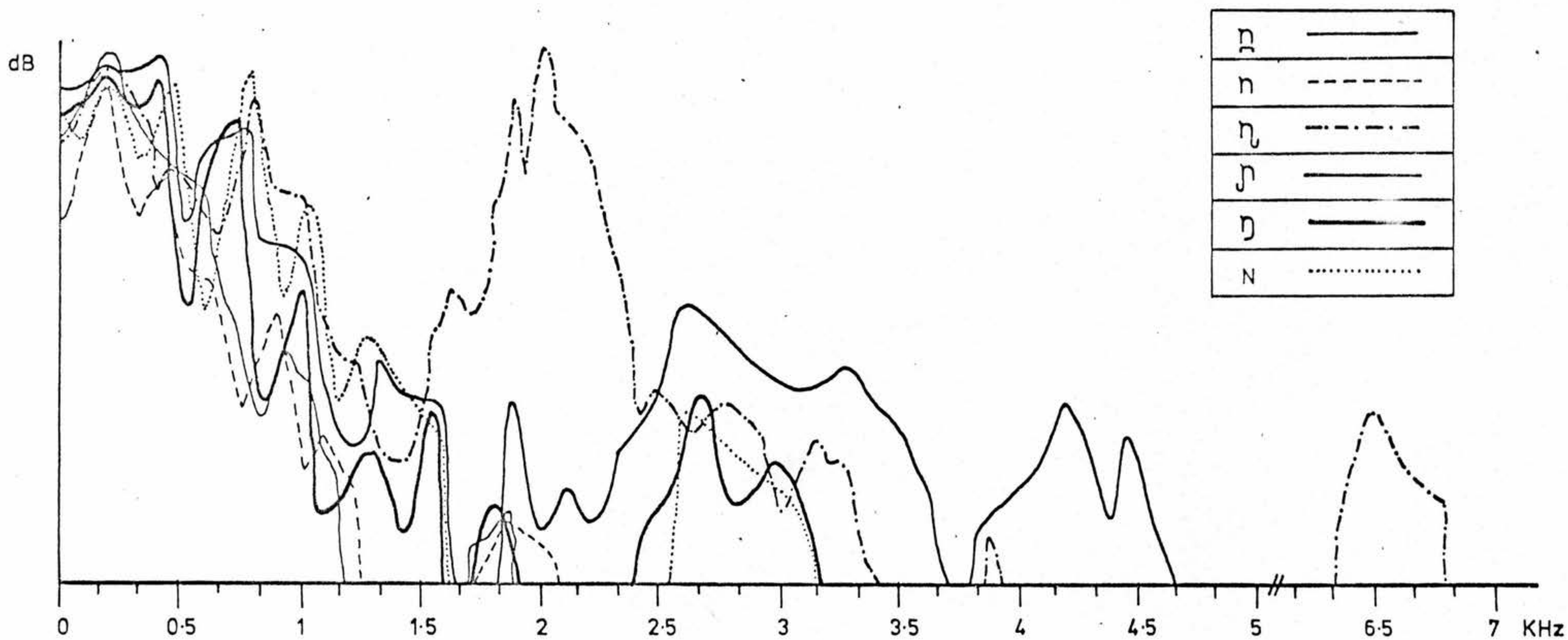


Fig. 16 Spectrographic sections of six different types of nasals, superimposed for comparison.

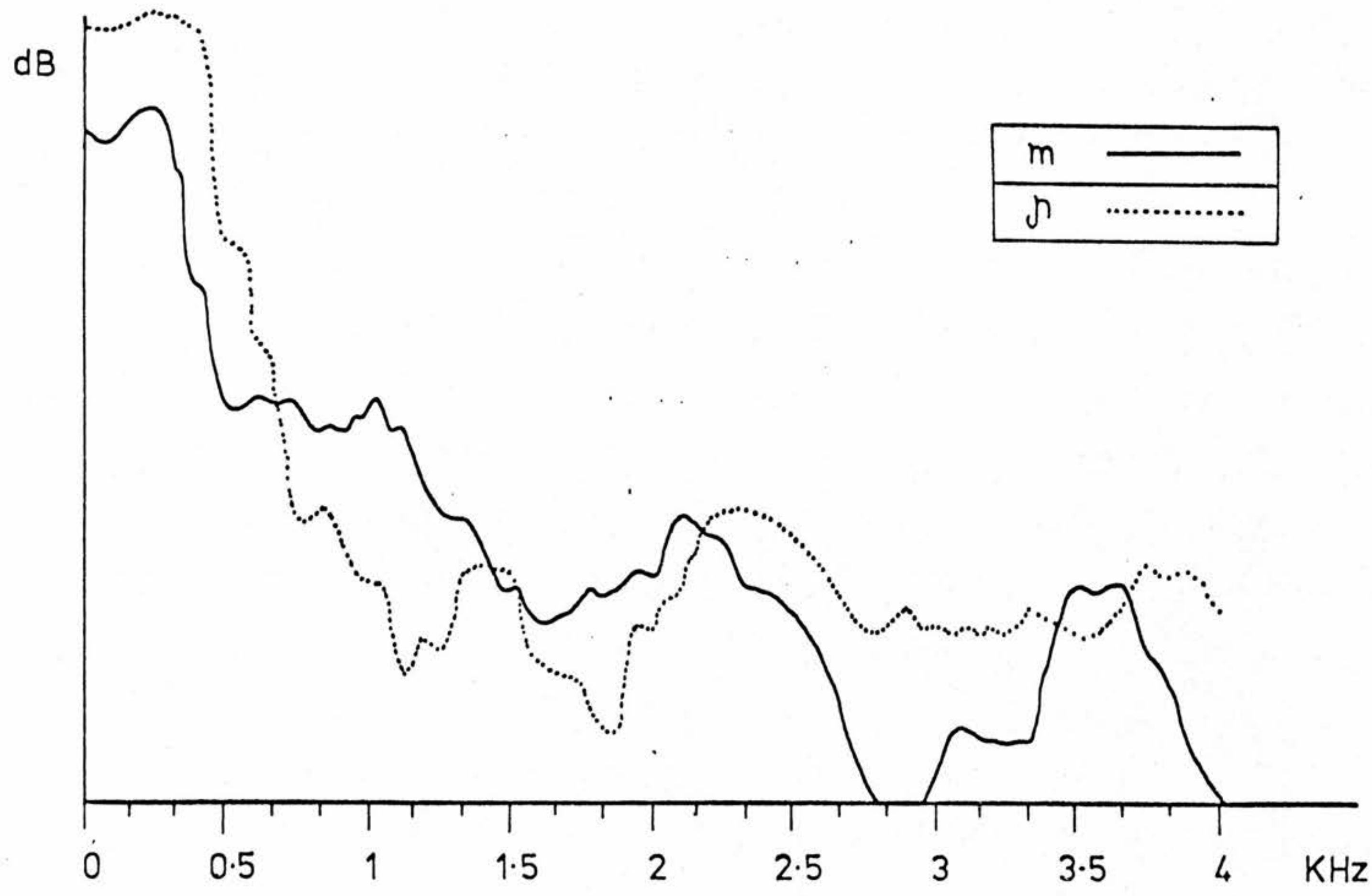


Fig. 17 Spectrographic sections of a bilabial and a palatal nasal, superimposed for comparison.

NASALS	POLES	ZEROS	CUT-OFF
n̪	250 1,750 2,750	$\frac{1,100}{1,600}$ $\frac{1,900}{2,500}$	3,000
n	250 1,750	$\frac{1,250}{1,600}$	2,000
ɲ	250 2,500 4,250	500 1,200 $\frac{1,500}{1,750}$ 2,000 3,600	4,750
ŋ	250 1,500 2,500	500 $\frac{1,600}{1,750}$ $\frac{1,850}{2,300}$	3,200
ɴ	250 750 2,500	500 $\frac{1,500}{2,400}$	3,200
m	250 1,000 2,200 3,700	500 1,500 $\frac{2,750}{3,000}$	4,000
ɳ	250 750 2,000 2,750	500 1,200 2,500 $\frac{3,250}{6,300}$	6,800

Table 2 Pole and zero values for seven different types of nasals. Two numbers separated by a horizontal bar, represent the estimated values of the bandwidth of the antiresonance.

The antiresonance reading was carried out at the lowest point of the most noticeable valleys of the spectrum and by locating the zones of the spectrum where there was no acoustical energy at all. In Table 2 two numbers with a horizontal bar between them represent the beginning and the end of the zones of the spectrum where the acoustical energy was zero. A number, which is not separated by a horizontal bar from an adjacent number, characterizes the lowest point of a noticeable valley in the spectrum. The energy cut-off point is also given. With the exception of the palatal nasal, all the nasal consonants have a very clear damping effect upon the high frequencies. The dental and alveolar nasals are particularly characterized by a dramatic damping of high frequencies, starting as low as 2,000 cps in the case of the alveolar nasal. All nasal consonants have in common the typical location of formant one around 250 cps. The dental and alveolar nasals are the only nasals which do not have a noticeable antiresonance around 500 cps. A second formant appears as follows:

F - 2 :	[m]	:	1,000	cps
	[n̪]	:	1,750	cps
	[n]	:	1,750	cps
	[ɳ]	:	2,000	cps
	[ɲ]	:	2,500	cps
	[ŋ]	:	2,500	cps
	[ɴ]	:	2,500	cps

Since all nasal consonants have the same formant-one, they are differentiated into four sub-categories on the basis of the different location of the second formant, as follows:

sub-categories :	1.	[m]	1,000	cps
	2.	[n̪, n]	1,750	cps
	3.	[ɳ]	2,000	cps

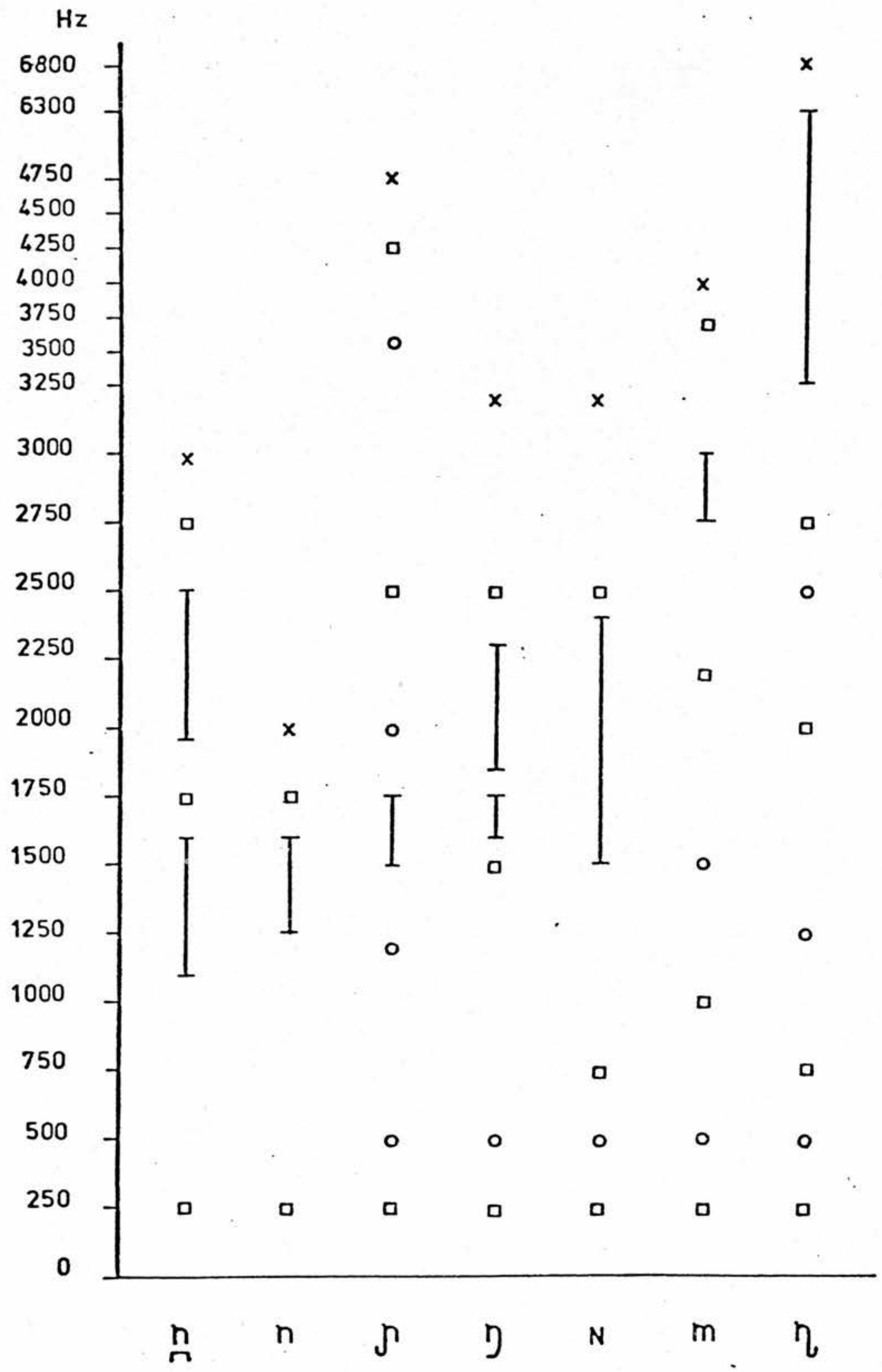
4. [ɲ, ŋ, ɴ] 2,500 cps

The data also reveal that the role played by the antiresonances is important in differentiating one nasal consonant from another. The location of the zeros goes up in frequency in a scale corresponding to the following order: [n̪, n, ɲ, ŋ, ɴ, m, ɳ] as illustrated in Fig. 18 . The retroflex nasal shows a more vocalic-like spectrum than the other nasals. The velar and uvular nasals are strikingly similar, except for a small pole formed close to formant one in the case of the uvular nasal, and around 1,000 cps in the case of the velar nasal.

Chapter 3 : The Acoustics of Nasalized Vowels

When a vowel is nasalized, the effect on the spectrum caused by adding nasal resonance is more clearly demonstrated. In a study comparing oral and the corresponding nasalized vowels, Joos (1948) observed the following: the normal F-pattern of the oral vowel is weakened in the spectrum of the nasalized vowel; there are nasal resonances between the oral formants which vary in frequency according to the vowel; there are other nasal resonances present in the vicinity of the oral formants. The nasal formants, therefore, do not have fixed and constant frequencies, but occur parallel to the variations in the oral formants, along the time axis. He concluded that a nasalized vowel is an oral vowel upon which nasal resonances have been superimposed.

Delattre (1969a, 1969b) suggested a distinction between two types of processes in producing nasalized vowels, besides noting the fact that nasalized vowels have nothing in common with the nasal



□ Formant

o Antiformant

I Location of zero acoustic energy in the spectrum

x End of acoustic energy distribution in the spectrum

Fig. 18 Formant and antiformant distribution for seven different types of nasals.

consonants, except the lowering of the velum, and the sharing of audible nasality, as we already mentioned earlier.

A nasalized vowel is characterized by a F-1 with very low intensity at about 500 cps, according to Delattre. The low intensity of F-1 is caused either by a damping effect, when the velum is lowered and the airflow passes through the nasal cavity, or by a cancellation effect, i.e., by a drastic reduction of the harmonics in the low frequency zone. The damping effect weakens the intensity and spreads the bandwidth of the harmonics. The cancellation effect occurs when the pharyngeal cavity is adjusted to equal the volume of the nasopharynx, so that the nasopharynx produces antiresonances and eliminates the harmonics of F-1. Both processes (damping and cancellation) can be responsible for the weak F-1 of nasalized vowels. Delattre points out that the degree of nasality varies according to the process used. He says:

> "Acoustically, intensity reduction of the first formant can be observed in two measurable forms on spectrograms: cancellation and damping. These two forms produce the same type of subjective effect, but at different degrees - cancellation actually eliminates some harmonics; damping merely spreads the condensed harmonics over a wider frequency band" (Delattre 1969a: 83).

According to him the most favorable process for creating perceptually distinct nasality is the cancellation process (Delattre 1969b: 115).

Delattre based his analysis on data from French, but he mentioned the nasalization that occurs in English and in Portuguese. The French nasalized vowels are nasalized by the cancellation process. All of them are low vowels ([ɛ̃, œ̃, ɑ̃, ɔ̃]), and they have the same F-1, because articulatorily, the volume of the pharyngeal cavity equals the volume of the nasopharynx. The nasalization of high vowels is usually produced by damping, according to Delattre, because their articulation makes it difficult to adjust the pharyngeal cavity volume to the volume of the nasopharynx. Moreover, the same type of nasalization is typical of contextually nasalized vowels. Delattre says:

> "When the subjective reduction of loudness is produced by damping, the first formant widens without appreaciable change in total amplitude - the number of harmonics increases and the amplitude of each harmonic decreases. It is this damping phenomenon that can be observed in the nasalization of the close vowels [ĩ, ẽ, õ, ũ] - as they nearly appear in Portuguese - or in the non-distinctive nasalization produced by the anticipation of a nasal consonant, as it occurs in English. In fact, the two procedures, cancellation and damping are not always separable and may well occur simultaneously, and therefore accumulatively, in the loudness reduction of the first formant which makes nasality audible" (Delattre 1969a: 87)

The process of nasalizing a vowel is shown most significantly by the changes that occur in the region of F-1. Because of the location of the nasal cavity connected to the top of the pharyngeal cavity, nasalization primarily influences F-1, or the 'throat resonance' (Joos 1948). Jakobson et al (1952) point out that a nasalized vowel has weak first and second formants and an additional nasal resonance between them. However, for open vowels (since they have a very high F-1), the nasal resonance occurs below formant one. Joos (1948) came to the conclusion that the range in the spectrum in which nasalization has an effect, occurs up to F-3, and that anything above it must be regarded as a non-typical feature.

The pole and zero distribution in nasalized vowels depends primarily on the acoustic structure of the corresponding oral vowel and on the different degrees of coupling.

The oral articulation and the degree of velic lowering are intimately related and interdependent. It is a well-known fact that the velum has smaller coupling area for close vowels and a large coupling area for open vowels (see Part III, Chapter 5).

The manipulation of synthetic speech has revealed that a close vowel changes its spectrum towards the spectrum of a nasalized vowel with less 'acoustic coupling' than an open vowel, as discussed earlier. Although some investigators have found changes in the frequency of F-1 of a nasalized vowel, changing occasionally the basic quality of the vowel when nasalization occurs, nevertheless, other investigators have come to the conclusion that a nasalized vowel does not necessarily need to have such change in F-1 frequency (see Ohala 1975: 294 for specific references).

The reduction in the intensity of F-1 is one of the most remarkable changes caused by nasalization, as we have already seen. Schwartz says:

> "The magnitude of the reduction range (sic) from 7 dB for [i] to 13 dB for [u]. The effect is thought to be largely the result of the addition of the damping characteristics of the nasal cavity wall surfaces" (Schwartz 1968: 136).

Fant (1960) observed that the effect of nasalization upon intensity can affect a vowel following a nasal. This vowel will usually have 2 dB less intensity following a nasal consonant, than following a non-nasal consonant, ceteris paribus. Delattre (1969a, 1969b) observed that the role of the low intensity of F-1 in characterizing nasalization is so important that a reduction of 18 dB, for instance, in a synthesized [ε] vowel, sounds like [ε̃]

Schwartz (1968) suggests that the measurement of overal intensity could be used to set up objective measures for nasalization in vowels.

Another clear effect caused by nasalization is the increase in the bandwidth of the formants. House and Stevens (1956: 221) observed an increase in the bandwidth of a nasalized vowel from 150 cps to 200 cps in the area of 400 cps, and to 500 cps in the area of 3,000 cps.

Because the nasal cavity functions as a side branching tube in nasalized vowels, the spectrum will have some special antiresonances associated with the coupling. Schwartz (1968: 136) presented the following locations of antiresonances in some nasalized vowels:

antiresonances	:	[ã]	:	2,400 cps
		[ĩ]	:	2,100 cps
		[æ̃]	:	1,400 cps

In addition to antiresonances, nasal coupling causes the reinforcement of some frequencies, producing special nasal resonance bands, usually very weak in intensity, in the spectrum of nasalized vowels. About these resonances, Schwartz comments:

> "Like the antiresonances, the frequency positions and relative amplitude of extraresonances vary with the vowel, the speaker, and the size of the velopharyngeal opening" (Schwartz 1968: 136).

To achieve auditory naturalness in synthetic syllables involving nasal consonants plus oral vowels, Mártony (1964: 30) found that the vowel must at least start nasalized. When the vowel is [a], the initial vocalic nasalization is crucial to generate a 'good' syllable. For [i] the nasalization is less important, and for [u] even less important.

Some notes on the acoustics of oral and nasalized monophthongs in Brazilian Portuguese are presented next.

A special investigation was conducted to study the variations between the monophthong [a] compared with the monophthong [ɜ̃], both realisations of /a/.

The acoustic spectrum of the monophthongs [a] and [ɜ̃] are given in Fig. 19. The spectral envelopes of the two vowels are superimposed in the lowest diagram to show more clearly how [ɜ̃] is different from [a] in BP. Both vowels were extracted from the word <u>amanhã</u> /ama'ɲaN/ [amɜ'ɲɜ̃] (tommorrow) uttered by myself, [ɜ̃] representing the final vowel of the word. The first formant is very close in both vowels, being slightly higher in the case of [a]. They differ in relation to formant-two, [a] has formant-two around 1,200 cps, and [ɜ̃] around 1,500 cps. The antiresonance of [ɜ̃] around 1,200 cps is noticeable. It is interesting that, in this case, the nasalized vowel did not show a typical damping effect upon the higher formants, on the contrary, the nasalized vowel has a higher intensity level compared with the oral vowel, at least in the frequency range from 1,500 cps up to 4,000cps. There is also a noticeable wide flattened band of high intensity acoustic energy ranging from zero to 1,250 cps in the case of [a]. Low vowels, in general terms, have a tendency to display F-1 with wide bandwidth, even when said orally. When they are nasalized, they tend to have even larger F-1 bandwidth. In the present investigation, the vowel [a] was said without perceived nasal quality, as judged by a BP speaker, but it occurs in a context (preceding a nasal consonant) when slight nasalization may commonly occur. In fact, the wide flattened bandwidth of F-1 of [a] would more likely to be expected in the case of a (slightly) nasalized occurrence of it

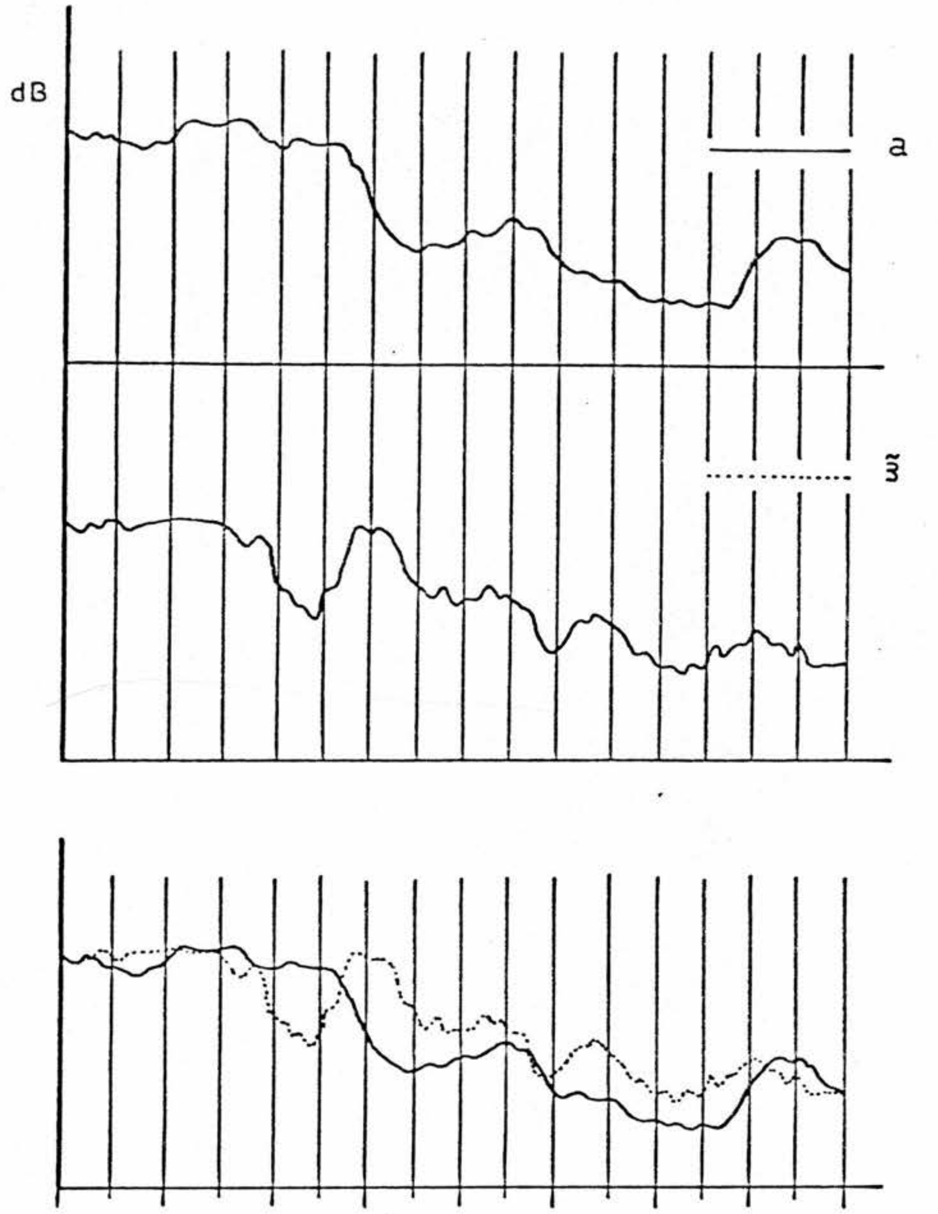


Fig. 19 Spectrographic sections of the monophthongs [a] and [ɜ̃] from Brazilian Portuguese, separately (upper diagrams) and superimposed (lower diagram) for comparison.

than in the case of an oral pronunciation of the same vowel.

In a further investigation, the acoustic values of formants 1, 2 and 3 of oral and nasalized monophthongs from Brazilian Portuguese have been estimated from wide band sonagrams of a large number of sentences uttered by three different speakers. Two speakers (B and L) are from São Paulo, and one speaker (P) is from Pernambuco.

The estimated values of formants 1, 2 and 3 of oral monophthongs from BP are given in Table 3, and the values of formants 1, 2 and 3 of nasalized monophthongs are given in Table 4. It must be said that the figures reported in Tables 3 and 4 represent an approximation of the values of formant 1, 2 and 3, bearing in mind that the method used for collecting these figures involves limitations. The figures represent, in fact, the best judgement possible of the basic formants using wide band sonagrams, leaving aside the occurrence of nasal formants. The three formant values for each monophthong represent the three lowest bands of greatest darkness on the sonagram.

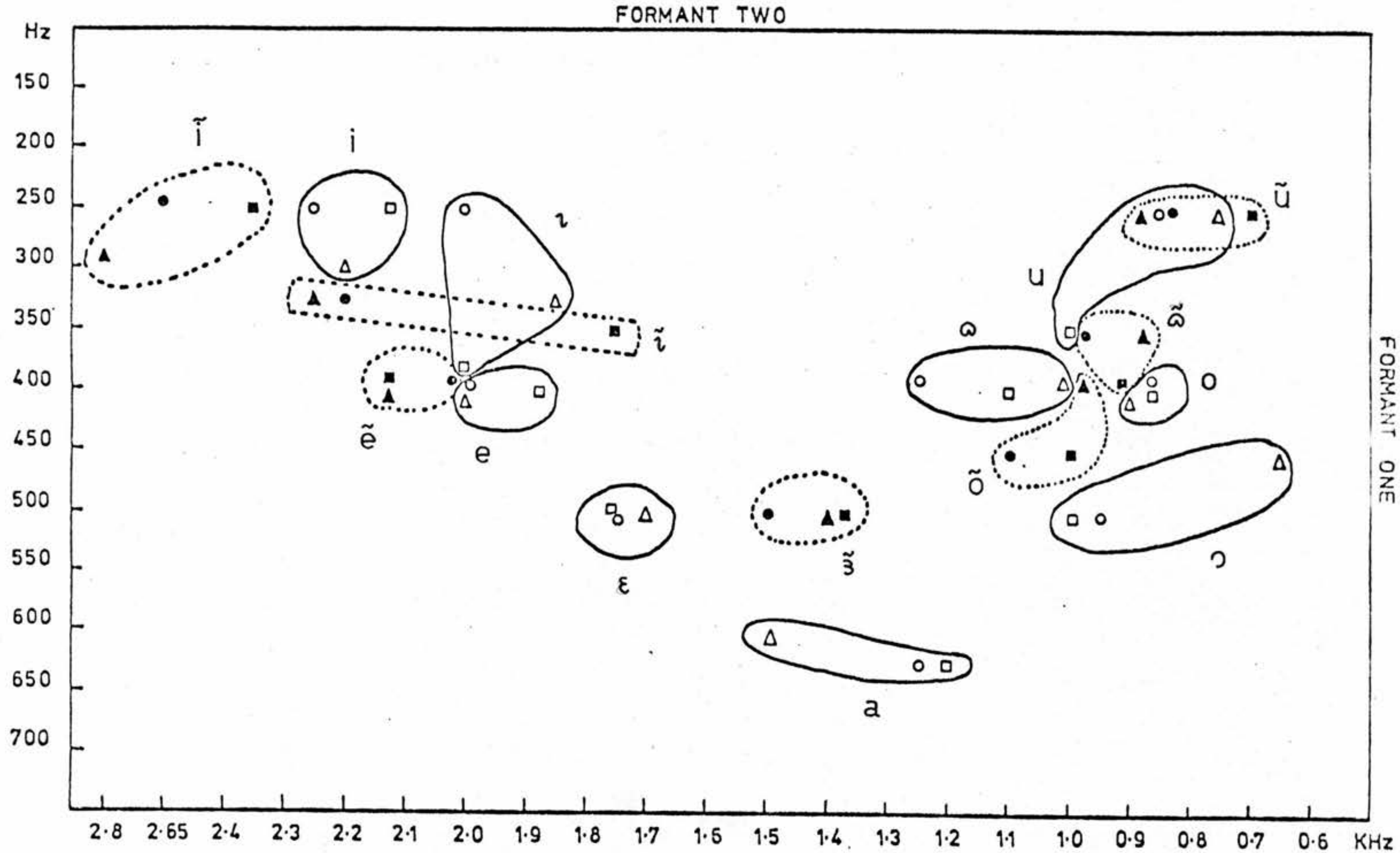
The data for formant 1, 2 and 3 given in Tables 3 and 4 are also displayed on Fig. 20, where formant-one is plotted against formant-two. In Fig. 20, ■ represents the speaker (P), ● represents the speaker (B), and ▲ represents the speaker (L). It is interesting that such a plot produces an arrangement of vowels which is very similar to the auditory assessment of them as displayed on the cardinal-vowel diagram given in Part I, Chapter 1, Section 1.8.1. (a).

VOWEL	SUB JECT	FORMANT 1	FORMANT 2	FORMANT 3
i	P	250	2,125	3,250
	B	250	2,250	3,500
	L	300	2,200	3,100
ɩ	P	375	2,000	3,250
	B	250	2,000	2,750
	L	325	1,850	2,500
e	P	380	1,875	3,250
	B	370	2,000	2,500
	L	400	2,000	2,250
ε	P	500	1,750	2,350
	B	500	1,750	2,500
	L	500	1,700	2,300
a	P	625	1,200	2,250
	B	625	1,250	2,375
	L	600	1,500	2,100
ɔ	P	500	1,000	2,125
	B	500	950	1,900
	L	450	650	2,300
o	P	375	875	——
	B	380	875	——
	L	400	950	2,400
ω	P	400	1,100	2,250
	B	375	1,250	——
	L	370	1,000	2,250
u	P	350	1,000	2,250
	B	250	850	1,750
	L	250	750	2,000

Table 3 Frequency values of formants 1, 2 and 3 of oral monophthongs from Brazilian Portuguese, estimated from wide band sonagrams of sentences uttered by three different speakers.

VOWEL	SUB JECT	FORMANT 1	FORMANT 2	FORMANT 3
	P	250	2,350	3,400
ĩ	B	250	2,650	3,500
	L	300	2,800	3,400
	P	350	1,750	2,250
ι̃	B	350	2,200	2,800
	L	375	2,250	3,000
	P	380	2,125	3,500
ẽ	B	375	2,000	2,600
	L	400	2,125	2,750
	P	500	1,375	3,250
ɜ̃	B	500	1,500	2,500
	L	500	1,400	2,300
	P	400	900	2,250
õ	B	350	1,000	2,750
	L	350	875	——
	P	450	1,000	2,125
ω̃	B	450	1,100	2,250
	L	370	1,000	——
	P	250	700	2,500
ũ	B	250	850	——
	L	250	875	——

Table 4 Frequencies of assumed formants 1, 2 and 3 of selected nasalized monophthongs from Brazilian Portuguese, estimated from wide band sonagrams of sentences uttered by three different speakers.



o,△ Speakers from São Paulo

□ Speaker from Pernambuco

Fig. 20 Two formant plot of oral (solid line) and nasalized (dotted line) monophthongs from Brazilian Portuguese.

Chapter 4 : Perceptual Features of Nasality

4.1. Vocalic Quality Change due to Nasalization

It is not rare to find researchers pointing out the fact that a vowel tends to change its quality when nasalized. Joos (1948), for instance, reported that in his investigation, the vowel [ε] when nasalized, sounded like [æ̃] , i.e., the vowel quality became lower. He found, by looking at the spectrogram of [æ̃] (nasalized [ε]), that the average F-1 plus the first nasal resonance (considered to be a single formant with a broad bandwidth) and the second nasal resonance were located inside the area of frequency which characterizes the vowel [æ]. Fant (1960) reported that experiments with the line analogue LEA showed that the coupling of the nasal cavities to the oral cavity produces a shift in F-1 sufficient to change the quality of the vowel when nasalized. He concludes by pointing out that it is necessary to make compensatory adjustments to maintain the same vocalic quality when the sound is nasalized. This means, for instance, that the nasalization of [a] to produce [ã] does not involve the lowering of the velum alone, everything else being constant, but it is also necessary to have some articulatory compensation in order to avoid the quality of the vowel changing to a shwa.

The distortion introduced by the coupling of the nasal cavity to the oral system changing the quality of the vowel when nasalization is superimposed, was also observed by Fujimura and Lindqvist. They say:

> "A vowel formant can be annihilated by an antiformant in some cases such as nasalization, giving perceptual effect of deviation from the vowel-like quality" (Fujimura and Lindqvist 1971: 541-588).

The most common observation concerning the change in quality of a vowel due to nasalization is found in the phonological literature, where many people have suggested a universal tendency for nasalized vowels to be lower in quality than the corresponding oral counterparts (see, for example, Chen 1973: 235). Straka says:

> "A nasalized vowel is always more open than the corresponding oral vowel, and once a vowel becomes nasalized, it tends to become more open too" (Straka 1955: 248; the translation is mine - see Appendix 1 (g)).

However, as Ruhlen (1974) pointed out, French is the only known language in which this tendency can be found. Ruhlen noted the following occurrence of nasalized vowels in the phonological system of the languages he investigated:

types of nasalized vowels	numbers of languages	
high-mid-low	37	
high-low	8	
high-mid	4	
mid-low	3	(French and 2 dialects of Breton)
mid	2	
low	1	(a Breton dialect)
high	0	

See Ruhlen (1973: 273). If the tendency for nasalized vowels to be lowered is a universal tendency, we would expect many more languages to occur with mid and low nasalized vowels and fewer to occur with high nasalized vowels.

Delattre's distinction between vowels, nasalized by cancellation or by damping, is used by him to explain why the French vowels are lowered when nasalized, while the Portuguese vowels, for example, do not manifest such a tendency. According to him, nasalized vowels in French are nasalized by the 'best' process, i.e. by cancellation, and therefore, all nasalized vowels have the same F-1. This fact makes the distinction between different nasalized vowels weakened (auditorily more difficult or masked), since only F-2 and F-3 are involved in their differentiation. Hence, the cancellation process used to produce nasalized vowels in French explains why the nasalization process has an effect of lowering the vocalic quality of the nasalized vowels in that language. Delattre makes comments on the Portuguese nasalized vowels, saying:

> "We find the same kind of nasalization, caused by the simple lowering of the velum, in a language such as Portuguese, where nasal vowels have remained relatively high: [ĩ, ẽ, ə̃ , õ, ũ] the large pharyngeal cavity not having adjusted to the volume of the velar cavity... We might ask, of course, why the Portuguese nasal vowels have not evolved in the same way as the French nasals. The answer seems simple. Portuguese has preserved until this day a tendency to close syllables which has prevented the complete loss of preconsonantal nasal consonants and restrained the evolution of the preceding vowel" (Delattre 1969a: 95-96).

In this way, he explains why Portuguese nasalized vowels do not share the cancellation process with the French nasalized vowels, and consequently do not have the tendency to lower the vocalic quality of the vowels when nasalized.

4.2. Perceptual Features of Nasality

Since Visible Speech by Potter et al. (1947), the importance of transitions over the F-pattern in the perception of different types of nasals has been a well established fact. Potter et al. said that spectrograms of nasal consonants without transitions cannot be used to predict what type of nasal has been analysed. More specificaly, they pointed out that the F-2 transition gives the crucial cue for differentiating the nasal consonants. Cooper et al. (1952: 265, 271) obtained good synthesized nasals when combining the transitions of stops with a fixed nasal F-structure. Liberman et al. (1954: 326, 328) did the same, but achieved better results when leaving F-1 without any transition at all. They also reported that F-2 transition produces a more reliable perceptual cue for stops than for nasal consonants. Fujimura (1962) emphasizes the importance of the F-structure of nasal consonants in their identification, although he recognizes that transitions must play an important role as well, as we already mentioned before. Malécot (1956) conducted a series of well-known experiments at the Haskins Laboratories on the perception of nasal consonants whose findings have been confirmed by subsequent investigations (see, for example, Nord 1976a). His study produced many interesting results, and it seems worthwhile to report them here in more detail.

In experiments involving synthetic speech, some features of nasal consonants emerged clearly. The most significant finding was that the nasals (like the stops) are distinguished from one another by the transitions of the adjoining vowels and not by their F-patterns. The syllables [ma, na, ŋa] were synthesized with F-1 at 240 cps, F-2 at 1,800 cps and F-3 at 2,040 cps. The transitions to the following vowel [a] were the same as those used to synthesize oral syllables with initial stops: [ba, da, ga] , with the only difference that, in the case of the stops, F-1 presents a long point bending down to reach the baseline of the spectrum, whereas in the case of the nasals, such a point does not exist, and F-1 is completely steady as a straight horizontal bar. Leaving the transitions off, the F-pattern of the nasals shows a steady state configuration. They had been weakened in intensity and F-1 had its bandwidth doubled. From the tests with synthetic speech, three results were noted: 1) the transitions to the adjoining vowels are relevant for distinguishing one nasal from another, and are related to place of articulation; 2) nasal transitions are similar to the transitions of the corresponding stops, with the exception of F-1 which has no transition; 3) the nasal resonance (F-pattern) of nasal consonants acts as a class marker for nasality and may be the same for all nasal consonants.

Malécot studied the perception of nasal consonants in real speech data. To do this, he designed a set of tests using a tape-splicing technique. The experiments consisted of recorded syllables which were later reassembled in different combinations. The syllables were all CV or VC types, where the vowel was [æ] and the consonants were bilabial, alveolar and velar nasals and stops. Both the original and the reassembled syllables were judged by English native speakers who were asked to identify the type of nasal they heard in each case. Some of his results are presented briefly as follows:

1) In a test with isolated nasal consonants, the judgements were:

for:	[m]	:	96 %	recognized as	[m]
	[n]	:	56 %	recognized as	[n]
			42 %	recognized as	[m]
	[ŋ]	:	12 %	recognized as	[ŋ]
			60 %	recognized as	[m]

In spite of the big variation in judgements, the nasal resonances alone are sufficient to provide some information about the place of articulation of nasal consonants in real speech data.

2) He got some interesting results in a second test, where new syllables were built up from the nasal resonances from one syllable and the vowel [æ] plus the transitions from a second syllable containing a different nasal consonant. In general terms, the bilabial nasal can be identified by its nasal resonances alone; the velar nasal can be identified only when the velar transitions are present, and the alveolar nasal can be distinguished from the velar nasal by the nasal resonances alone, but to be distinguished from the bilabial nasal, the alveolar nasal needs its alveolar transitions.

3) A further test to check the reliability of the selected cuts showed that some confusions in the previous tests were due to a lack of accuracy in splicing the transitions, but the difference was not significant.

4) Reassembled syllables made up of nasal resonance and the vowel [æ] plus the transition of the corresponding stops, showed that the transitions play a very significant role in differentiating the nasal consonants.

5) In a final test with new syllables whose segmental cuts were controlled by spectrographic records, the average of correct identification rose. In the case of consonant plus vowel patterns, the bilabial nasal resonances prevailed over the transitions; the alveolar nasal resonances prevailed over the transitions of the velar nasal, but the bilabial nasal transitions prevailed over the alveolar nasal resonances. In the case of the velar nasal, the transitions prevailed over the nasal resonances. He also observed that in real speech, the nasal transitions in vowel plus consonant patterns, were twice as long as in consonant plus vowel patterns.

The results with real speech can thus be summarized as follows:

a) transitions are the principal cues for identifying nasal consonants; b) the nasal F-pattern or nasal resonances also contribute to the identifcation of different types of nasal consonants; c) the F-pattern of nasal consonants is more effective in the identification of nasal consonants in syllable final position, than in syllable initial position.

Finally, Malécot suggests that, because of the importance of the transitions in the perception of nasal consonants, they are better classified as nasal stops than as continuants, nasalization being a feature of the syllable rather than of individual segments.

Recently, Nord (1976a) carried out an experiment on the perception of the nasals following Malécot's work. He used a much more accurate technique (with the help of a computer program) to produce the samples to be tested. The results showed a high correlation with Malécot's findings.

In an investigation of the perception of nasality using a speech segmenter, which I have conducted, interesting and sometimes surprising findings have been produced. A report of this investigation is given in the next section.

4.3. Investigations with an Electronic Speech Segmenter

4.3.1. Introduction:

The aim of the investigation described in this section, was to study the interaction between duration and the phonetic quality of pieces of utterances isolated with strict control over their beginning and end points. Another aim was to carry out a delicate segmentation of some selected words to study the perceptual distribution of nasality over segments in BP.

In this study, an Electronic Speech Segmenter, developed in the Phonetics Laboratory of the University of Edinburgh, was used. The present report focuses mainly on the details of the phonetic composition of these words, relating some aspects of their phonetic quality to their perceived and measured duration in words, with particular reference to the occurrence and nature of nasality.

4.3.2. Material and Method:

The Electronic Speech Segmenter is a device which cuts out from the speech signal, a period of acoustic energy for a preselected duration. The time span of the 'segment' which is cut out from the acoustic signal may be varied within a range from 1 sec to 1 msec. The cut can be located anywhere in the utterance within a time interval of 1 sec. The acoustic signal containing the cut is displayed on an oscilloscope screen, and the utterance is replayed via a loudspeaker. Fig. 21 shows the instrumental set-up for the speech segmenter, and Fig. 22 shows the principal switches that are used in the speech segmenter to control the location and duration of the cuts.

The cuts are controlled by two clocks. The time span of the cut is handled by controlling the numbers with four figures in each clock. The first clock controls where the beginning of the cut will start in relation to a reference point triggered electronically. The second clock controls where the cut ends. Two replay systems are available. The utterance from which a 'segment' of selected duration has been cut-out may be replayed, or the process may be inverted, so that only the cut-out segment is reproduced.

Before describing the details of the investigation, a number of general points should be made. The speech segmenter is primarily useful for analysing and testing the perception of sounds as a

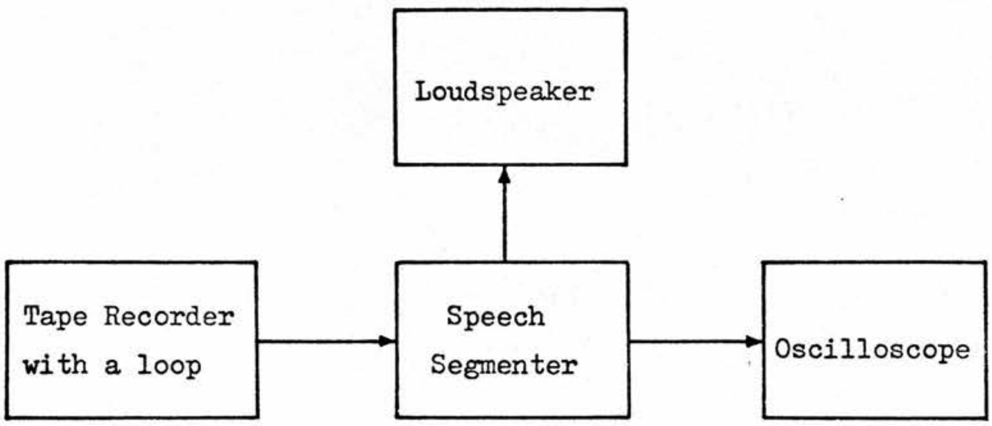
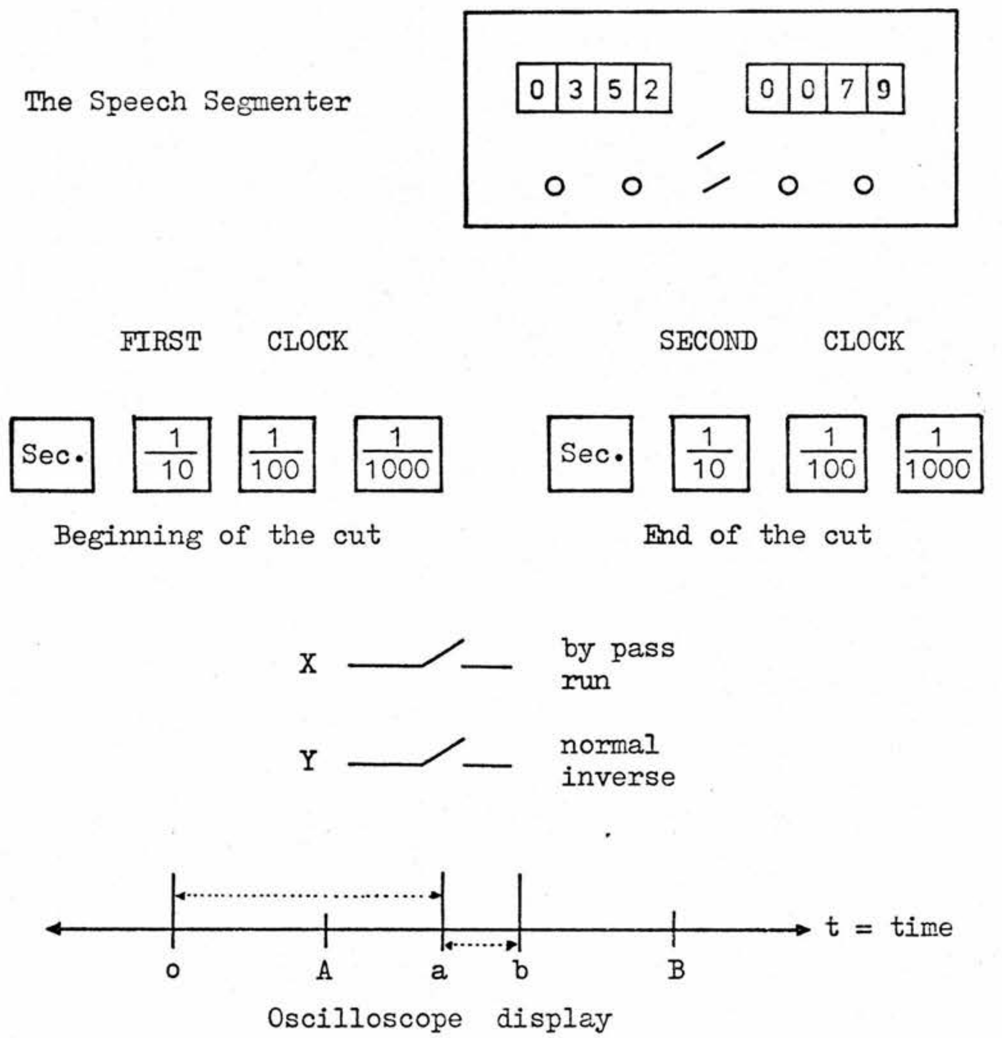


Fig. 21 Block diagram showing the experimental set-up used in connection with the speech segmenter.



CUTS		SWITCHES	
o	Reference point	X-off	no cuts
A - B	Utterance	X-on	with cut
a - b	Bandwidth of the cut	Y-off	the utterance is heard with the cut
o - a	Beginning of the cut	Y-on	only the cut is heard

Fig. 22 Schematic representation of how the Speech Segmenter controls the cuts.

function of time. In this respect, the speech segmenter is one of the most reliable devices for cutting out pieces of speech with considerable precision, in a way that the normal speed of a tape recorder does not allow.

Experience using this technique has shown that the perception of the phonetic quality of a segment is closely related to the duration of the segment concerned. Very short segments are usually perceived as noise, that is, with no easily identifiable phonetic quality. When the cut is not too brief, the beginning and the end of the cut are heard as something similar to an unreleased glottal stop. This is caused by the abrupt cut-off or onset at a point with high amplitude. The loudness at these points is felt to be strong, even when the cut is in an unstressed syllable. When the cut is very brief, the listener does not hear a break in the utterance, but rather the continuous utterance with a sharp noise within it.

It is possible to isolate and identify phonetically many different segments by cutting an utterance into small pieces, but the utterance as a whole is not perceived as the sum of all those pieces.

In the present investigation, the analysis of the phonetic quality of the replayed utterances was based on auditory assessments. By phonetic quality is meant one of the parameters commonly used for analysing and classifying sounds phonetically, i.e., nasality, degree of retraction, degree of fronting, degree of stricture, voicing, etc.

In this report, the term 'release' (unrelease) refers to the release (or not) of the oral occlusion that occurs during the articulation of stops and nasal consonants; the term 'glide' means any change in quality before or after a period of steady state quality of a sound, and the term 'noise' means a sound which is not perceptually characterizable as a speech sound.

The assessment of the phonetic quality of the pieces of speech reported here, was carried out by two phoneticians: the author and Miss F. Dechicha (whose mother tongue is not Brazilian Portuguese, but Algerian Arabic and French). The words under investigation were uttered by the author.

4.3.3. Discussion:

a) Investigation of <u>nenhum</u> /ne'ɲuN/ [nẽ͡ĩɲũŋ] (nobody):

The investigation started with a very large cut, so that the entire recorded word was cut out. Then by adding only 1 msec at a time, the first sound heard is a noise, as defined earlier. The beginning of the word was marked at the exact point when the first noise was heard. From this point, 10 msec were added at a time and the enlarged piece of speech was replayed. An auditory judgment was then made and noted in phonetic transcriptions when possible and in written comments. By this method, the whole word was analysed. The judgements reported here were made only at those points where there was a noticeable change in quality or duration.

A mingographic recording of the audio signal of the word <u>nenhum</u> is given in Fig. 23. The numbers of the segmental lines in Fig. 23 (and in Fig. 24), refer to the points of the utterance where a comment was made about the quality or duration of the replayed segment.

Comments:

1. start: first noise heard.
2. a nasal quality is heard.
3. the identification of an unreleased dental nasal.

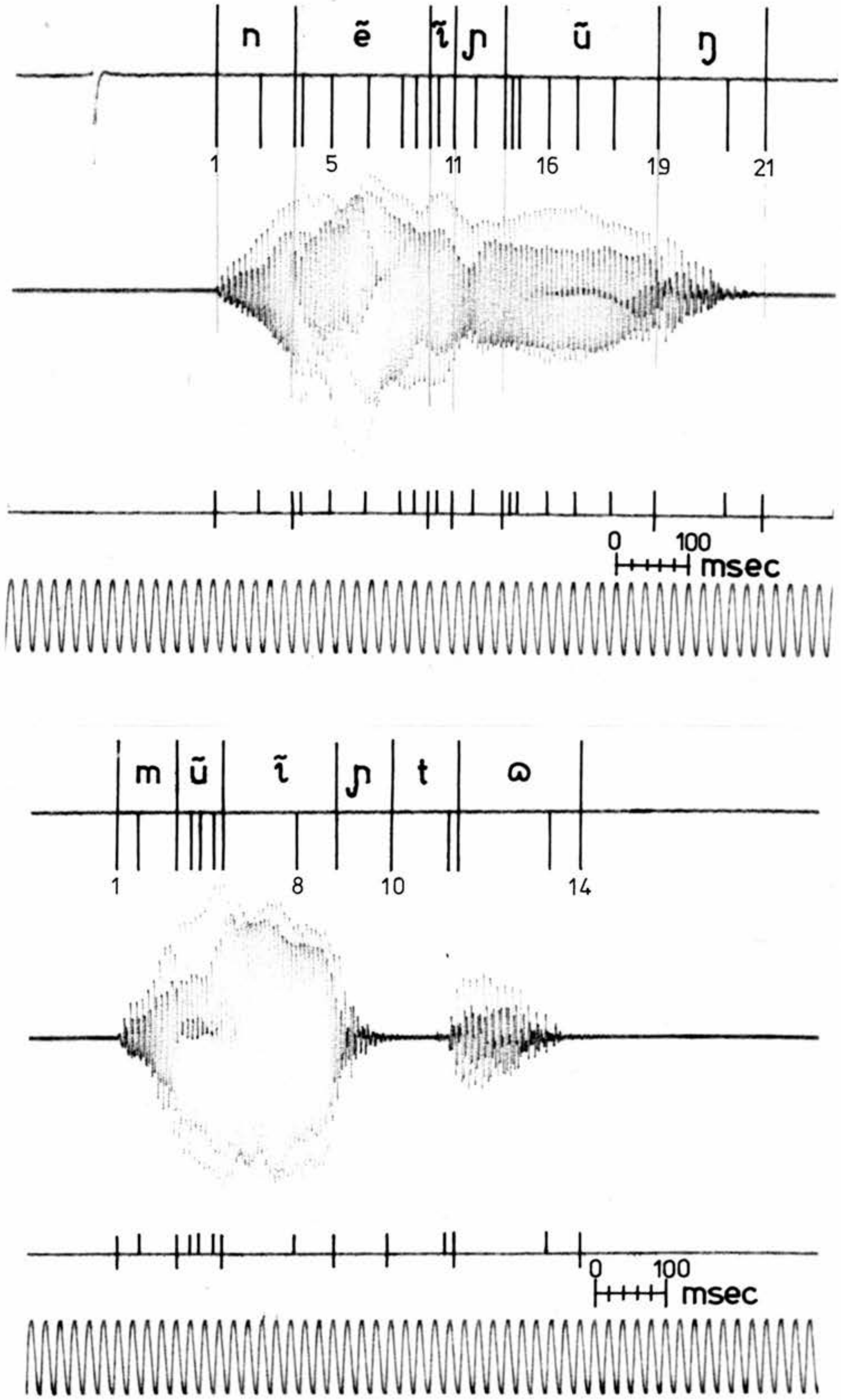


Fig. 23 **Mingographic recordings of the audio signal of the Brazilian Portuguese words <u>nenhum</u> (nobody) and <u>muito</u> (a lot), with the time marker (bottom) and the segmentation lines to show the location of the cuts as obtained using the speech segmenter.**

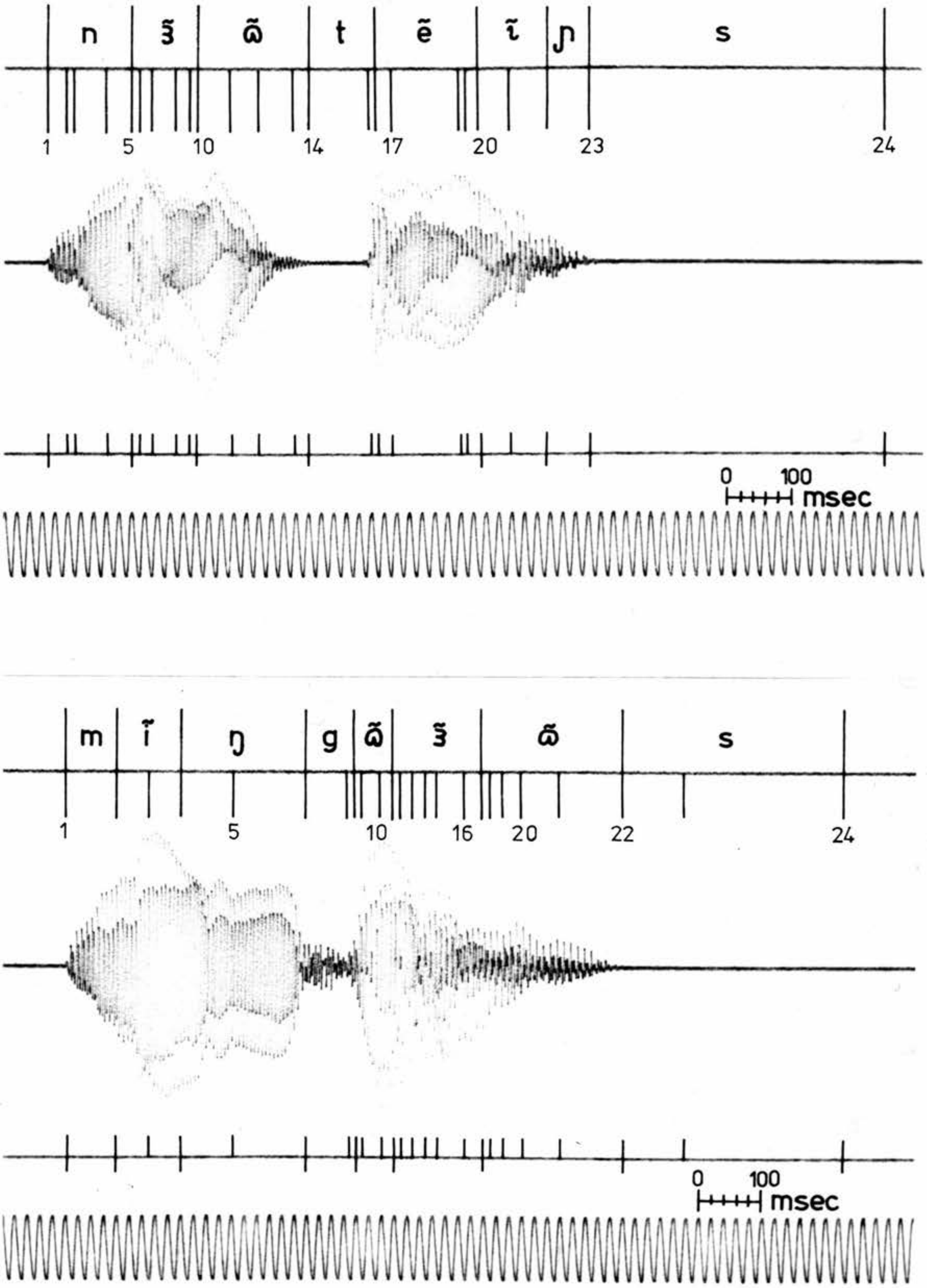


Fig. 24 **Mingographic recordings of the audio signal of the Brazilian Portuguese words <u>não tens</u> (you don't have) and <u>mínguãos</u> (nonsense word), with the time marker (bottom) and the segmentation lines to show the location of the cuts as obtained using the speech segmenter.**

4. the release of the dental nasal plus a very short vowel is heard.

5. the vowel is perceived as [e̞] and is not nasalized.

6. the vowel sounds more open and is not nasalized.

7. a glide towards a more close position is perceived, with nasalized quality.

8. the movement of the glide increases.

9. the direction of the glide becomes clearer, it has a palatal quality.

10. a diphthongized form [ẽĩ] is heard at the end of the replayed segment.

11. the diphthongal glide is still very short.

12. the diphthong is clearly audible and is followed by an unreleased nasal which is identified as palatal.

13. the release of the palatal nasal is audible but the following segment is unidentifiable.

14. the release allows the identification of an [u]-like sound after the palatal nasal.

15. a very short [u] appears, but is not nasalized.

16. the vowel is now nasalized and still very short.

17. a very clear and long [ũ:].

18. still the vowel [ũ:] with unchanged quality.

19. an unreleased velar nasal is now heard.

20. the velar nasal continues and when switched to inverse position in order to ascertain the end of the word, only a nasal quality is heard from point 20 onwards.

21. the final noise is located in the inverse position (the end of the word can only be located precisely when the device is switched to the inverse position).

The investigation revealed that the vowels perceived as nasalized in the word, when cut and reduced to a certain duration are perceived as oral and not as nasalized vowels (see below).

It is interesting to compare the nasalization onset timing of [ẽĩ] with that of [ũ]. In the case of [ẽĩ] , nasalization is perceived after only 100 msec from the vowel onset, being clearly heard at 150 msec; the whole diphthong was 190 msec long. In the case of [ũ] , nasalization is perceived only 50 msec after the vowel onset; the entire vowel was 300 msec long. It must be noted that the nasalization of the [ẽĩ] is not phonologically relevant, but the nasalization of the [ũ] is significant. The diphthong [ẽĩ] is 190 msec long, but the latter part of it, perceived phonetically as [ĩ] , is only 30 msec long.

The utterance was cut from points 1 - 3 and 19 - 21. With the segmenter switched to the inverse position, the stretch replayed was [ẽĩɲũ] with no nasal at the beginning or the end.

The speech segmenter was then switched back to the normal replay position so that only the beginning and the end of the word were running. The piece of speech bounded by numbers 1 - 3 revealed a clear dental nasal, but which was unreleased. The release of the nasal occurred when 10 msec was added, and the new stretch of speech allowed the identification of a following [e]-like sound. The piece of speech bounded by numbers 19 - 21 revealed a nasal without any auditory feature that could be attributed to a nasal of a specific place of articulation. A reduction in intensity was noticeable and the isolated segment gave the auditory impression of a humming with mid-low falling intonation. This piece of speech was clearly different from the preceding nasalized vowel and it sounded slightly pharyngalized.

We have noticed that a segment like the above, characterized by having nasal quality alone, could be found whenever nasality occurred before a pause, a stop or a fricative. We have called this type of 'segment' the 'nasal tail'.

A 10 msec cut in the centre of [ũ] was selected for further analysis; when replayed, this isolated piece of speech was heard as a short noise. Then 1 msec at a time was added to each side; the vocalic quality was perceived when the piece of speech achieved 20 msec in length. The vowel was perceived as nasalized, and we did not perceive the vowel without nasalization at any point. This is interesting since when the cut is taken only from the initial part of the vowel, this part of the vowel is perceived to be oral. If the cut is located in the centre of the vowel, this part of the vowel will not be perceived without nasality. The same test was repeated for [ẽ̞] and similar findings were obtained. The test was again performed for [n] , but in this case, at least 25 msec was needed in order to recognize the piece of speech as [n] . Compare this finding with the 50 msec which was needed to identify the same [n] when the cuts were made from the beginning of the nasal in word initial position. In that instance, double the duration of the isolated segment (i.e., 50 msec) was needed in order to recognize the nasal consonant when the segment started from the beginning of the utterance with the intensity level increasing. When the segment started from a location in the centre of the nasal with a steady intensity level, only 25 msec of the nasal was necessary in order to be identified as a nasal consonant. These observations suggest that intensity is an important factor in the perception of sounds as a function of time.

b) Investigation of muito /'muiNtu/ ['mũĩɲtɷ] (a lot):

A mingographic recording of the audio signal of the word muito is given in Fig. 23 with the segmentation lines showing the location of the cuts.

Comments:

1. start: the first audible noise is located.

2. a very short bilabial nasal is heard.

3. the release of the bilabial nasal; a vowel is heard with an [ə] quality. See position (1) in Fig. 25.

4. a vowel is heard at the end as specified by position (2) in Fig. 25.

5. the quality of the vowel is closer. See position (3) in Fig. 25.

6. the quality of the vowel is still closer and is slightly centralized. See position (4) in Fig. 25.

7. only now is the vowel in 3 - 7 heard as a nasalized vowel; a glide is heard at the end of the vowel with a central quality. See position (a) in Fig. 25.

8. a nasalized diphthong is heard. See (5)-(b) in Fig. 25.

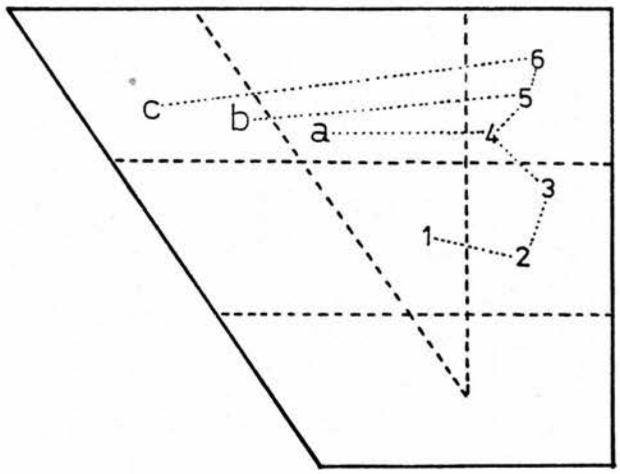
9. the beginning and end points of the diphthong now have a more peripheral quality. See (6)-(c) in Fig. 25.

10. an unreleased nasal with a quality between palatal and velar is perceived. In the inverse position, the beginning of the period of silence for the stop occurs. When 9 - 10 is isolated, the nasal is heard as a nasal tail; in inverse position, [ktɷ] is heard.

11. the stop is released: it sounds like a click [ǂ]

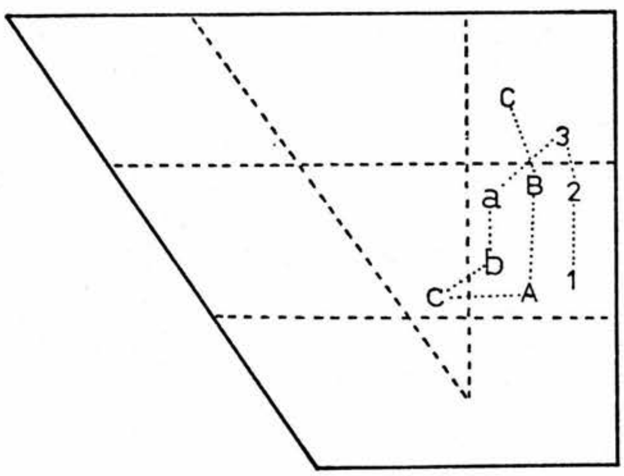
12. the stop is followed by a short and voiceless [u̥].

13. the vowel now has the quality [ɷ] . In the inverse position, the end of the vowel is heard as a whispered vowel [ɷ̥].



nasalized diphthong

[ũĩ] from muito



nasalized triphthong

[õɜ̃õ] from 'mínguãos'

Fig. 25 Vocalic quality change of the nasalized diphthong [ũĩ] (upper diagram) and of the nasalized triphthong [õɜ̃õ] (lower diagram), as perceived at successive points with the help of the speech segmenter (see discussion in the text).

14. the last noise is located in the inverse position.

The nasalization of the first part of the diphthong [ũĩ] was perceived only when a diphthongal glide was added. A nasalized diphthong [ũĩ] was heard from the point at 80 msec up to the point at 370 msec. But when switched to the inverse position to cut from the point at 370 msec backwards, we found that the cut from the point at 370 msec to 290 msec had the quality of a nasal between palatal and velar. This nasal, however, was not perceived as a nasal consonant in normal position, only when isolated in the inverse position. When the last 20 msec of this nasal was left (cut at 350 msec in the inverse position), the replayed segment was perceived as [ktʊ].

c) Investigation of <u>mínguãos</u> ['mĩŋgɐ̃w̃ʊ̃s] (nonsense word, but cf. <u>minguam</u> /'miNguauN/ ['mĩŋgɐ̃w̃ʊ̃] 'they wane'):

A mingographic recording of the audio signal of the word <u>minguãos</u> is given in Fig. 24 with the segmentation lines showing the location of the cuts.

Comments:

1. the first audible noise is located.

2. a bilabial nasal is identified. In the inverse position, there is no nasal.

3. the release of the bilabial nasal; after the nasal, there is a very short vowel perceived as [ɩ].

4. the vowel is closer: [i] ; it is not nasalized.

5. a nasal with a quality between palatal and velar is now heard. In the inverse position [ʔŋgɐ̃w̃ʊ̃] is heard.

6. in the inverse position, the nasal consonant is not perceived.

7. a voiced velar stop is heard following the nasal.

8. the release of the stop is heard, followed by a very short voiceless vowel. See position (1) in Fig. 25 (lower diagram).

9. the vowel is voiced and closer in quality, i.e., [o̝] See position (2) in Fig. 25. In inverse position, the velar stop is cut off, and [ʔõɔ̃õs] is heard.

10. the vowel has a closer quality: [o̝] . See position (3) in Fig. 25.

11. a glide is heard at the end of the vowel; the vowel is heard as an oral diphthong [oo].

12. the ending part of the diphthong is more open and centralized [ö̞] . See position (a) in Fig. 25.

13. the ending part of the vocalic movement is more open and centralized [ɔ̈] . See position (b) in Fig. 25.

14. the ending part of the vocalic movement is still more open and more centralized. See position (c) in Fig. 25.

15. the diphthong is still oral. In the inverse position, [ʔõɔ̃õs] is heard with surprisingly strong nasalization.

16. The first and the second syllables sound like two stressed syllables.

17. the diphthong is now heard as having the latter part nasalized.

18. a glide is heard at the end of the diphthong. In the inverse position, [ʔɔ̃s] is heard.

19. a nasalized triphthong is heard: [õɔ̃õ]. See position (A) in Fig. 25.

20. the final part of the triphthong has a closer quality; see position (B) in Fig. 25.

21. the final part of the triphthong has an even closer quality which is slightly centralized. See position (C) in Fig. 25.

22. the beginning of the friction of the [s] in the inverse position.

23. the short [s] sounds like an affricate [t͡s] when isolated from the point at 22 up to 23.

24. the last noise is located in inverse position.

When the 'segment' [mĩ] is cut off (from 0 to 180 msec), the velar nasal is perceived as a syllabic nasal, and seems to bear the principal stress of the word.

When a segment from 330 msec to 460 msec was replayed, a very surprising result was revealed. The segment was transcribed in the following way: [ˈyɠ o̥] i.e., with the cut mentioned above, the piece of speech related to the velar nasal was perceived as [y] (a round front vowel), the egressive velar stop was perceived as an implosive ~~ingressive~~ velar stop, and the voiced vowel at the end of the segment was perceived as a voiceless vowel.

d) Investigation of <u>não tens</u> /'nauN 'teNs/ [ˈnɜ̃õ ˈtẽĩɲs] (you don't have):

A mingographic recording of the audio signal of the words <u>não tens</u> is given in Fig. 24 with the segmentation lines showing the location of the cuts.

Comments:

1. start: the first audible noise is located.

2. a nasal quality is heard.

3. the identification of a very short [n]-like sound.

4. the nasal sounds like a syllabic dental nasal.

5. very short glide at the end; no vowel is heard.

6. release of the nasal plus a very short vowel.

7. the vowel is not heard as nasalized; the vowel is perceived as [ə˔].

8. the vowel starts to be heard as nasalized.

9. a glide appears at the end of the vowel.

10. the glide has an [u] quality; the onset of the vowel is more open and fully nasalized:

11. a clear nasalized diphthong; the ending part has an [o] quality.

12. in the inverse position, 12 - 14 sounds like humming (nasal tail).

13. the ending part of the diphthong is now attributed to [õ] and the diphthong is heard as fully nasalized.

14. in the inverse position, the beginning of the closure for the [t̪] is perceived.

15. still the same ['nɔ̃õ] ; there is no audible nasal at the end.

16. beginning of the release of the stop. It sounds like a very short ejective [t̪'] .

17. there is an [e]-like vowel following the release of the stop. In the inverse position, there is no perceptible stop.

18. the vowel following the stop is a long and non-nasalized [e] .

19. there is a glide at the end of the vowel.

20. the glide has an [ĩ] quality; the vowel [ẽ̞] is now perceived as nasalized.

21. a nasalized diphthong is heard: [ẽɪ̃].

22. a retracted palatal nasal is now heard. In the inverse position, 22 - 23 sounds like a nasal tail.

23. a fricative sound is now heard; the fricative is identified as [s].

24. the last noise is located in the inverse position.

The nasal identified as a dental nasal when 40 msec long, was perceived as a syllabic dental nasal when 90 msec long.

The initial part of the nasal diphthong identified as [ɜ̃] in <u>não</u>, was perceived as oral even when 50 msec long. It started to be recognized as nasalized only when the quality change associated with the latter part of the diphthong was introduced.

The perceived quality of the latter part of the diphthong [ɜ̃ʊ̃] varied according to the duration of the cuts, in the following manner:

cut at:	220 msec	:	beginning of the diphthongal change
	230 msec	:	[u]
	290 msec	:	[o]
	390 msec	:	[u]

We perceived a nasal tail from 330 msec up to 410 msec, and we tested the whole utterance with a cut from the beginning of the nasal tail at 330 msec up to the beginning of the release of [t̪] at 510 msec. It was observed that there was no perceptible difference in quality of the whole replayed utterance without the nasal tail. The cut was not recognized as a cut, and the utterance sounded normal. But, when the beginning of the cut was at 270 msec, and half of the latter part of the diphthong (identified as [ʊ̃]) was cut off, the utterance sounded emphatic with a very short diphthong ending sharply, followed by a long voiceless dental stop.

We could not identify auditorily any homorganic nasal before the stop, nor a prenasalized stop, only a nasal tail at the end of the diphthong.

4.3.4. Conclusion:

a) The speech segmenter revealed itself to be a useful tool for segmenting speech with reliable control over the cuts made.

This technique was controllable visually by looking at the display of the utterance on the oscilloscope screen, while providing facilities for the auditory assessment of different 'segments'. For example, the technique allows the listener to examine the perception of nasality in relation to the 'segments obtained by preselected control of the duration and location of the cuts.

b) The present investigation indicates that the perception of quality in speech is constrained by temporal factors. This means that the perception of a quality such as nasality in segments, may vary according to the duration of the segment. For example, a vowel which is perceived as a nasalized vowel when the entire duration of the vocalic segment is played, is perceived as an oral vowel when the vocalic segment is cut so that only a short duration of it is replayed.

c) The present study also suggests that acoustic intensity is an important factor in the recognition of phonetic quality in relation to its duration. For example, the recognition of the quality of a segment requires longer duration for it to be recognized with a specific phonetic quality, when isolated at the beginning of an utterance where acoustic intensity starts at a low level before increasing, than when isolated from the middle of an utterance where the acoustic intensity is at a higher and more constant level.

PART VI : INVESTIGATIONS OF VELIC MOVEMENTS AND OF AERODYNAMICS OF NASALITY

Chapter 1: An Experiment with Normal, Nasalized and Denasalized Voice

1.1. Introduction

The investigation about to be reported needs a few preliminary comments. We have pointed out earlier (Part III, Chapter 3 and 4) that airflow and nasality have no direct relationship. We have also pointed out (Part III, Chapter 3) that segmental nasality can be correlated with nasal airflow when there is a rather high level of airflow present on the nasal traces, although it must always be remembered that this correlation is not absolute. A high level of nasal airflow may indicate the possible presence of nasality, but it does not follow from this that different levels of nasal airflow can be related to different degrees of nasality. Furthermore, in the case when there is no excursion of the nasal trace from the baseline, this does not always mean that nasality was not present or could not be perceived. Nasality is after all an auditory concept and therefore an auditory judgement of it must accompany any other factor one wishes to investigate in relation to nasality. Pneumotachographic recordings (see Part VI, Chapters 2, 3 and 4) display not only the relative amount of nasal airflow, but also the presence or absence of nasal resonance. This makes such recordings a more reliable indicator of the presence or absence of nasality, or nasal resonance, with or without nasal airflow. In the present investigation, however, we have used an electrokymograph which does not give a reliable indication of the presence or absence of nasal resonance on its recordings, but gives us some information about the distribution of oral/nasal airflow in connected speech.

In the present experiment, we have studied the relationship between the auditory assessment of nasality, denasality and normal voice qualities and the distribution of oral and nasal airflow. Another aim of this experiment was to examine the consistency of the voice quality during the utterance of a short text. The subject was the author who trained himself to utter a short text in Portuguese with the three types of voice quality mentioned above. The recordings of these voice qualities (see Fig. 26) were judged to correspond to an auditorily well accepted performance of the text with the three types of voice quality. The text with the phonetic transcription for normal voice quality is given next.

Text: "<u>Minha terra tem palmeiras</u>
<u>Onde canta o sabiá</u>.
<u>As aves que aqui gorjeiam</u>,
<u>Não gorjeiam como lá</u>.

Phonetic transcription for normal voice:

['mĩɲa 'tɛɣa 'tẽɲ 'pɑɷ'meɩɾas
'õndɩ 'kɜ̃nta ɷ sabɩ'a
az 'avɩs kɩ a'ki goɹ̥'ʒeɩɜ̃ɷ̃ŋ
'nɜ̃ɷ̃ goɹ̥'ʒeɩɜ̃ɷ̃ŋ 'kõmɔ 'la]

1.2. <u>Discussion</u>

In the discussion which follows, the term nasality always refers to an auditory judgement of perceived nasality. The quality referred to as denasality is not a quality with complete absence of auditory nasality, for instance, replacing all nasal consonants by their corresponding voiced stops, but instead, denasality means a special sort of nasality, which is sometimes called 'cold in the head voice'.

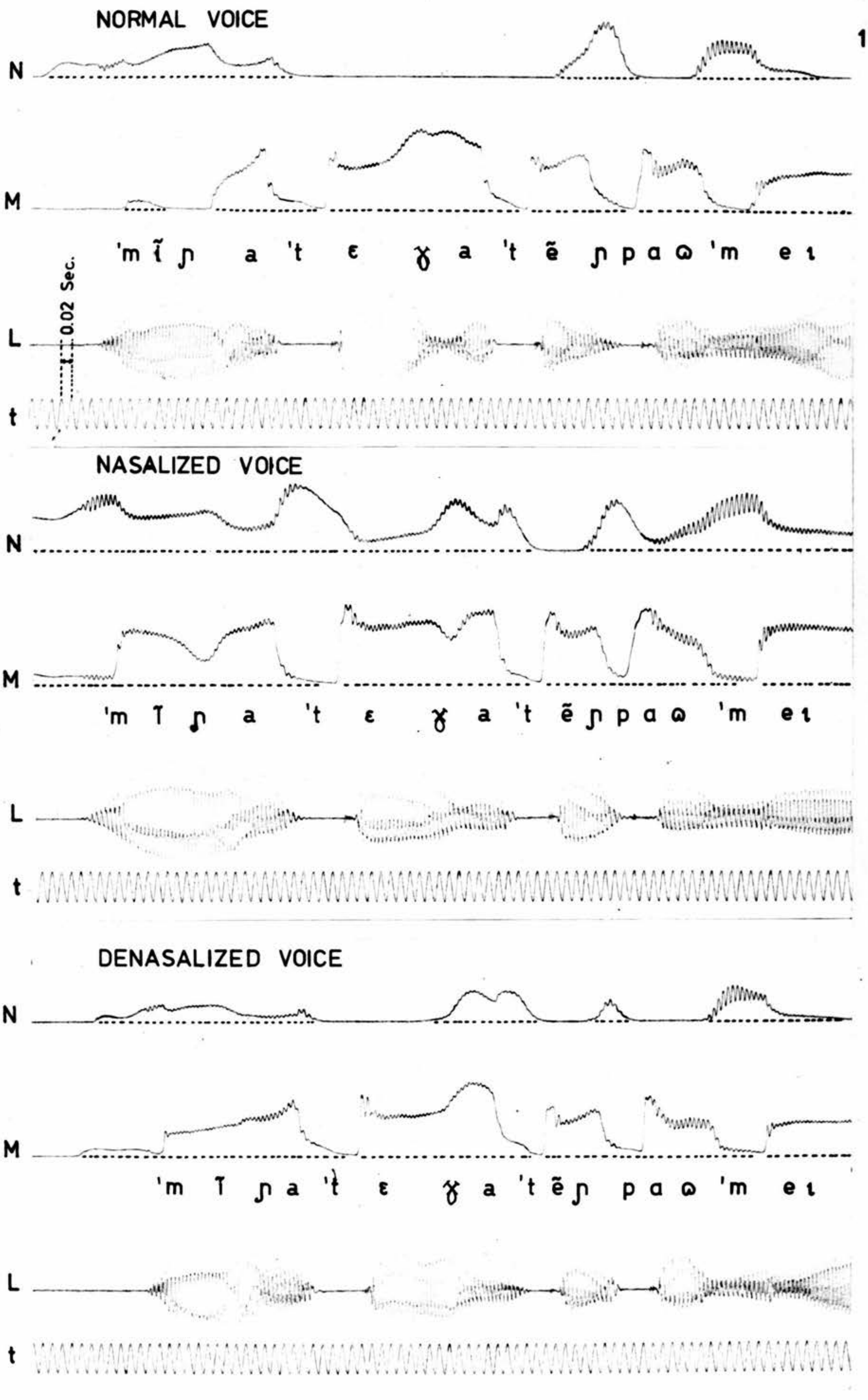


Fig. 26 Electrokymographic traces of a short text uttered with normal, nasalized and denasalized voice quality.

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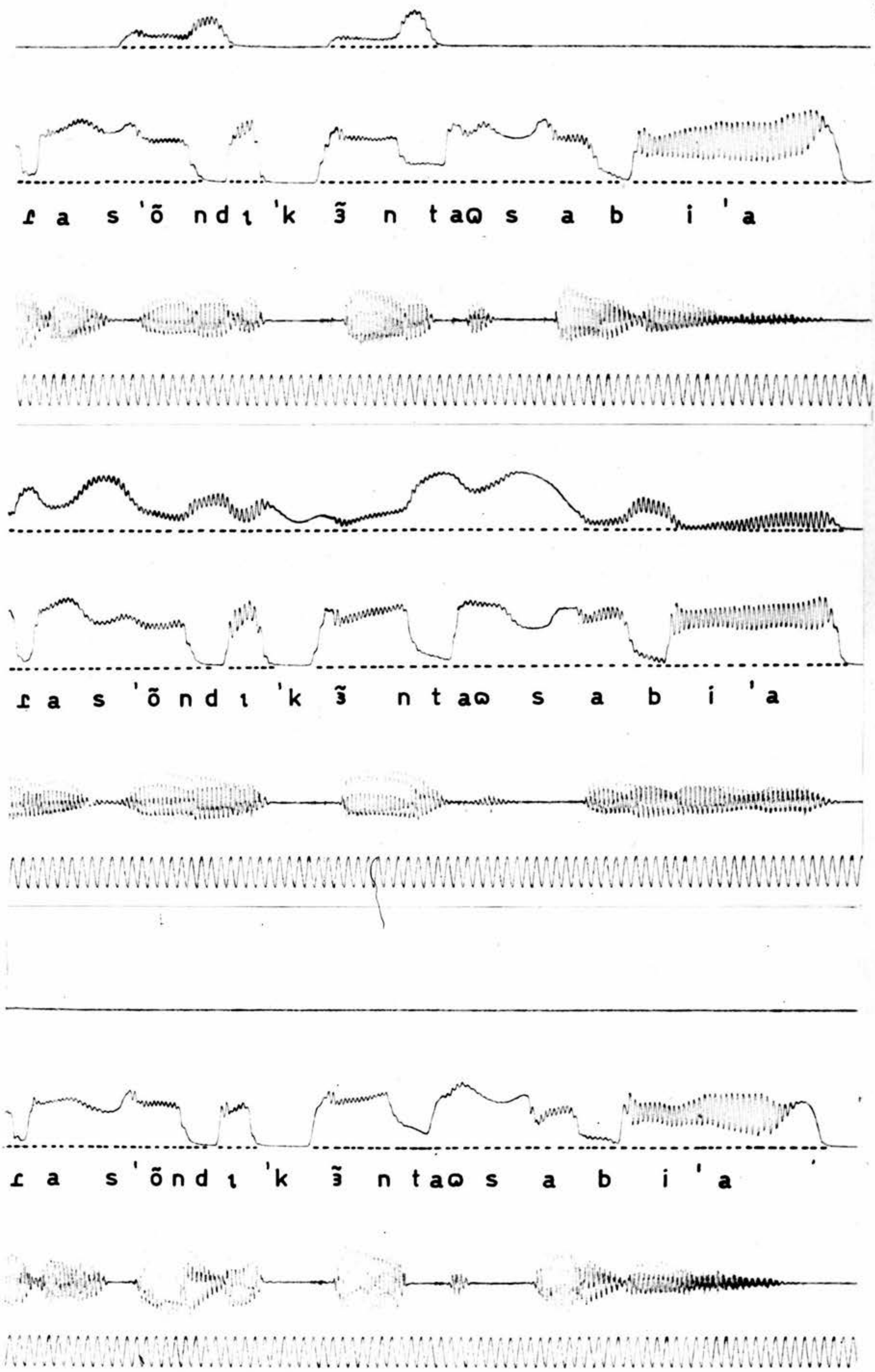
ɾ a s 'õ n d ɩ 'k ɜ̃ n t a ɷ s a b i 'a
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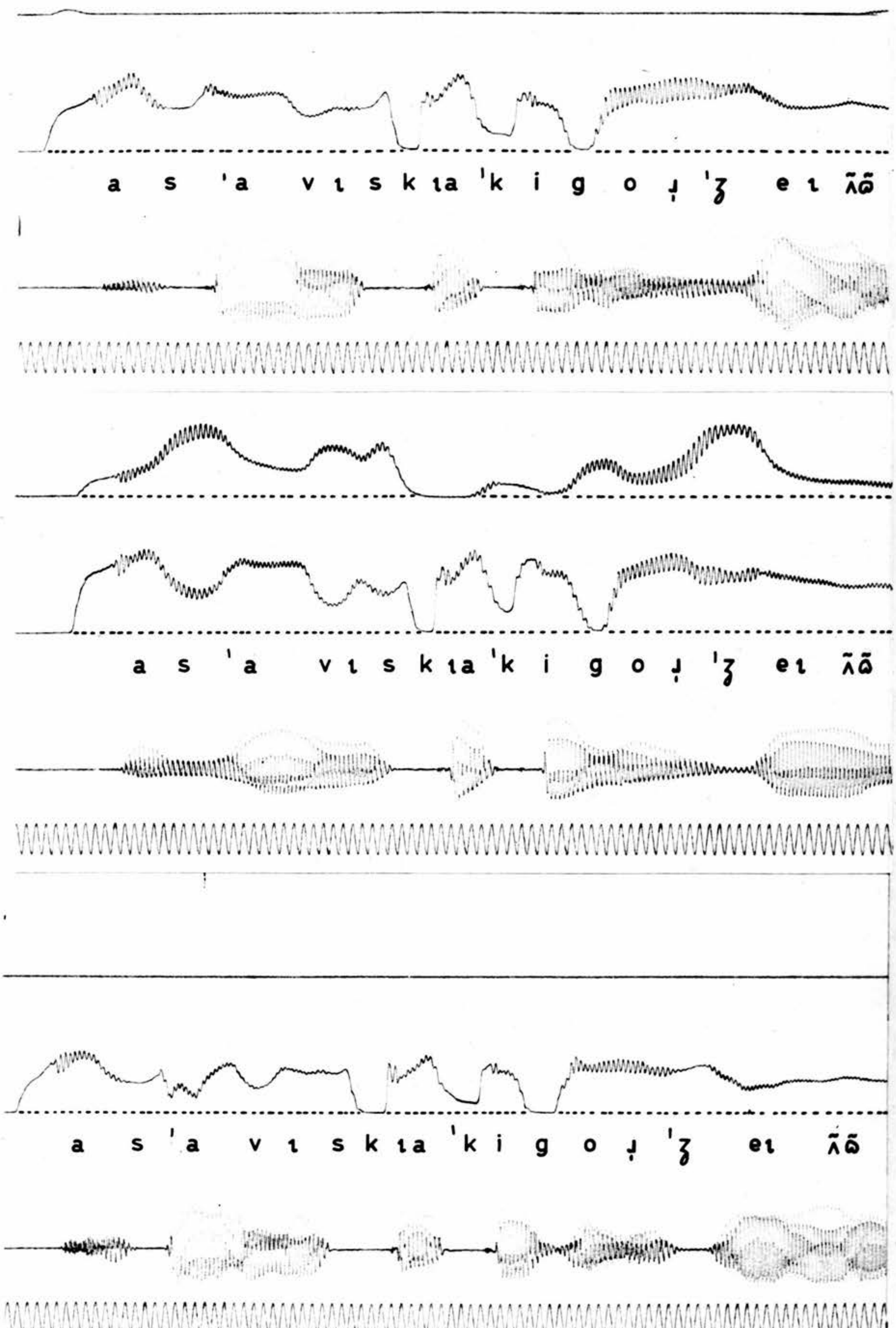
a s 'a v ι s k ιa 'k i g o ɟ 'ʒ eι
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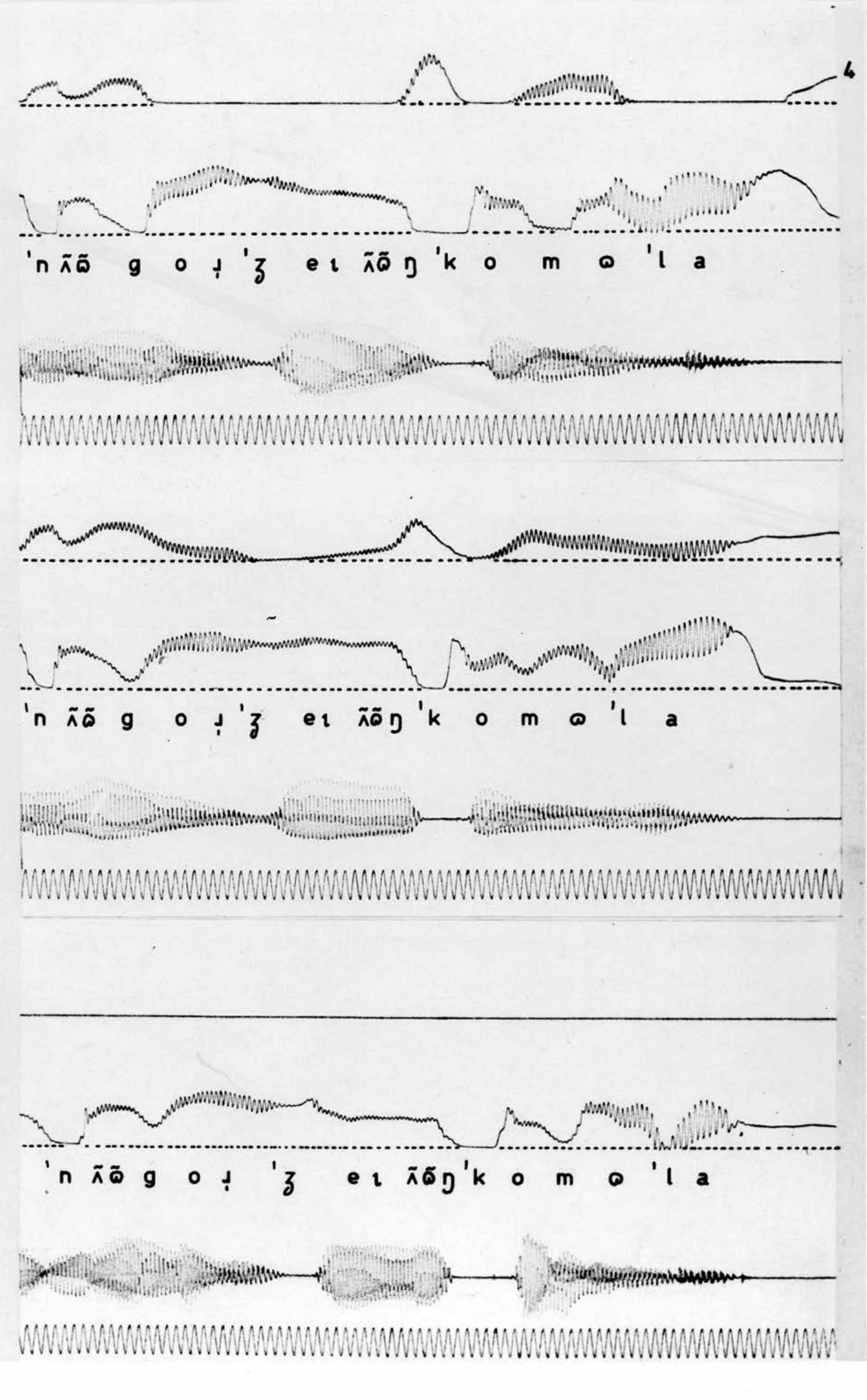
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'n ʌ̃ɷ̃ g o ɟ 'ʒ eɩ ʌ̃ɷ̃ŋ 'k o m ɷ 'l a
'n ʌ̃ɷ̃ g o ɟ 'ʒ eɩ ʌ̃ɷ̃ŋ 'k o m ɷ 'l a
'n ʌ̃ɷ̃ g o ɟ 'ʒ eɩ ʌ̃ɷ̃ŋ 'k o m ɷ 'l a

In denasalized voice, the nasal consonants and the linguistically nasalized vowels do not sound like stops or oral vowels, but they have a peculiar quality, similar to the speech of a person with a bad cold and stuffed nose. We will now proceed with the analysis of the kymographic traces of perceived nasality, denasality, and normal voice.

1.2.1. Normal Voice:

The distribution of nasality was typical, that is, segments which were expected to be nasalized were in fact nasalized, and segments which were expected not to be nasalized, were not nasalized at all. The oral segments showed no excursion from the baseline on the nasal airflow channel, and the nasalized segments (including the nasal consonants) showed a positive excursion on the nasal airflow channel.

1.2.2. Nasalized Voice:

The text starts with a nasal consonant plus a nasalized vowel, followed by another nasal consonant. The perceived nasality started from the beginning and was maintained throughout the entire text. However, the nasal airflow trace was not maintained at a steady level. On the contrary, the nasal channel showed a remarkable variation of amount of nasal airflow for different sounds in the case of nasalized voice (see Fig. 26). At certain points in time, the nasal airflow was so low that it touched the baseline. This happened during the articulation of [t] in <u>tem</u>, of [k] in <u>que</u>, of [ʒ] in the second occurrence of the word <u>gorjeiam</u>, and in the articulation of [o] in <u>como</u>.

1.2.3. Denasalized Voice:

During the initial part of the text, the nasal traces were similar to the normal voice traces except that the level of nasal airflow when present, was lower than in normal voice, and the subject pronounced the syllable [ɣa] with noticeable amount of airflow present in the nasal trace. After the [m] of palmeiras, until the end of the text, there was no airflow recorded at all in the nasal trace, only a baseline with no deviations at all.

1.2.4. General remarks:

The text presented two pauses: one after sabiá, and the other after lá, at the end. Before both pauses, it was noticed that the vowel preceding the pause showed a tendency to be voiceless in the case of normal and denasalized voice, but the vowel was clearly voiced in nasalized voice. The consonant of liaison between as aves was voiceless in normal and denasalized voice, but it was voiced in nasalized voice. The realization of the palatoalveolar fricative in gorjeiam, in both occurrences of the word, was uttered as a voiceless fricative in the case of denasalized voice, whereas in normal voice this segment was voiced.

1.2.5. Investigation of nasal airflow:

To study the variations in the nasal airflow in the case of nasalized voice compared with normal voice, we computed the amount of nasal airflow present in the nasal trace of the two voices. A reading was made for each segment using an arbitrary scale in millimetres, with zero at the kymographic baseline. When there was more than one segment of the same kind, a statistic average of the values for all occurrences was calculated. The graph in Fig. 27 shows the distribution of all segments of the text with their relative amount of nasal airflow in normal and nasalized voice. Nasalized voice disclosed a higher level of airflow for the nasal consonants than normal voice. [p, t] had higher level of nasal airflow than [b, d],

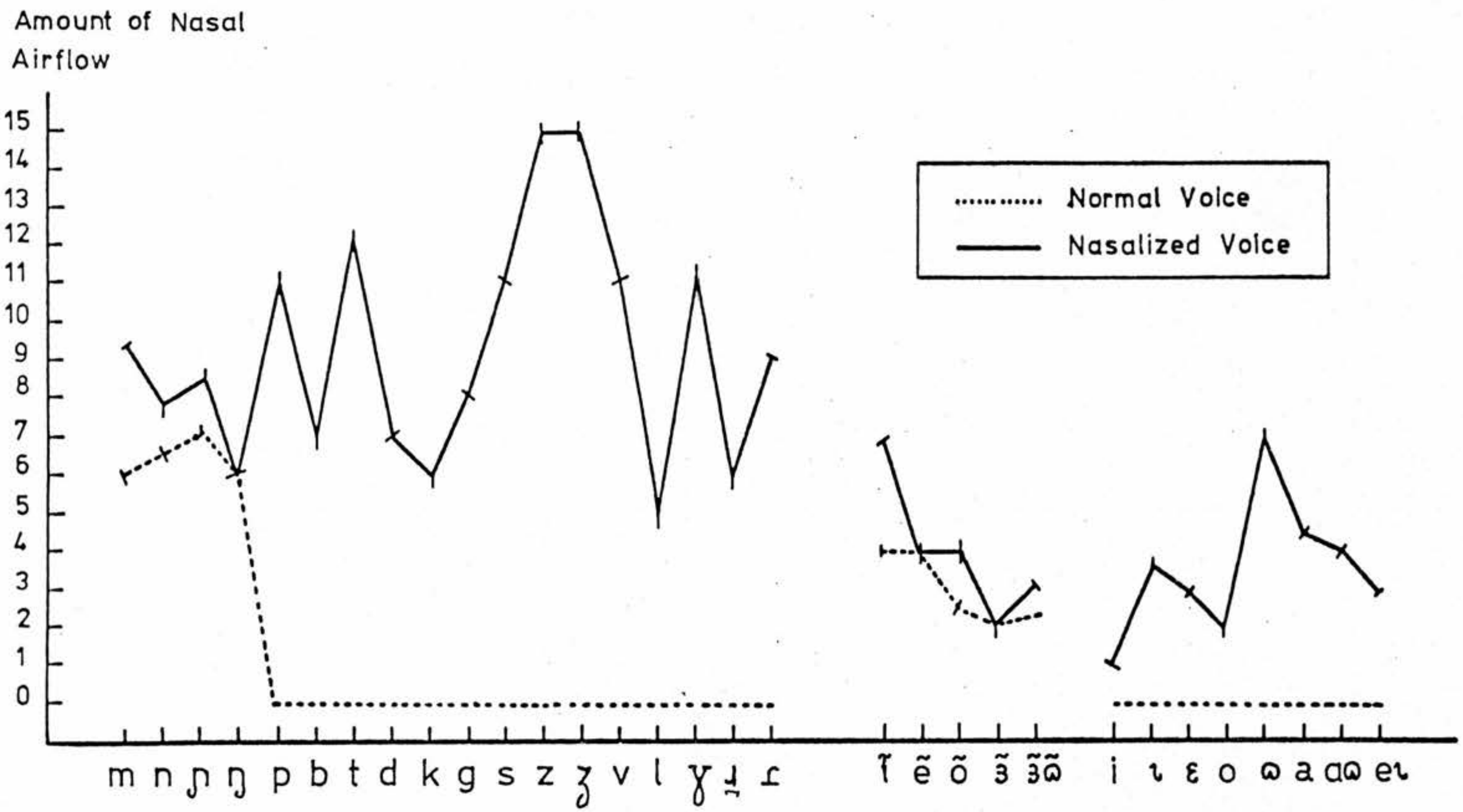


Fig. 27 Distribution of amount of nasal airflow in an arbitrary millimetric scale (ordinate) for the segments of a short text uttered with nasalized and normal voices.

but [g] presented higher level of nasal airflow than [k] when they were pronounced with nasalized voice. The fricatives [s, z, ʒ, v, ɣ] revealed the highest level of nasal airflow in the case of nasalized voice. [l] and [ɹ̰] disclosed the lowest level, and [ɾ] presented a level in between [t] and [d] .

The behaviour of the relative amount of nasal airflow in the case of the vowels, under the two different voice qualities, indicated that either in normal or in nasalized voice, the BP nasalized vowels present a distribution of nasal airflow directly proportional to the vocalic height. So, a close vowel has a higher level of nasal airflow than an open vowel. On the other hand, the BP oral vowels that have no nasal airflow in normal voice, did not present a direct correlation with vocalic height in nasalized voice. The vowels [ɑ] and [a] disclosed very high levels of nasal airflow. Finally, we must point out the fact that, in general, nasalized voice revealed a higher level of nasal airflow for the vowels than normal voice. This finding supports the suggestion made earlier (Part III, Chapter 5) that a nasalized voice is a disruption of the velic scale used to produce normal voice.

1.2.6. Investigation of oral airflow:

To study the variations in the oral airflow in the case of the three different voice qualities, the amount of airflow present in the oral kymographic traces was computed. A reading was made for each segment using an arbitrary millimetric scale, with zero at the kymographic baseline. When there was more than one segment of the same kind, a statistic average of the values for all occurrences was calculated. Fig. 28 shows the distribution of all segments found in the text with their relative amount of oral airflow. In Fig. 28, □ represents normal voice, ○ represents nasalized voice, and △

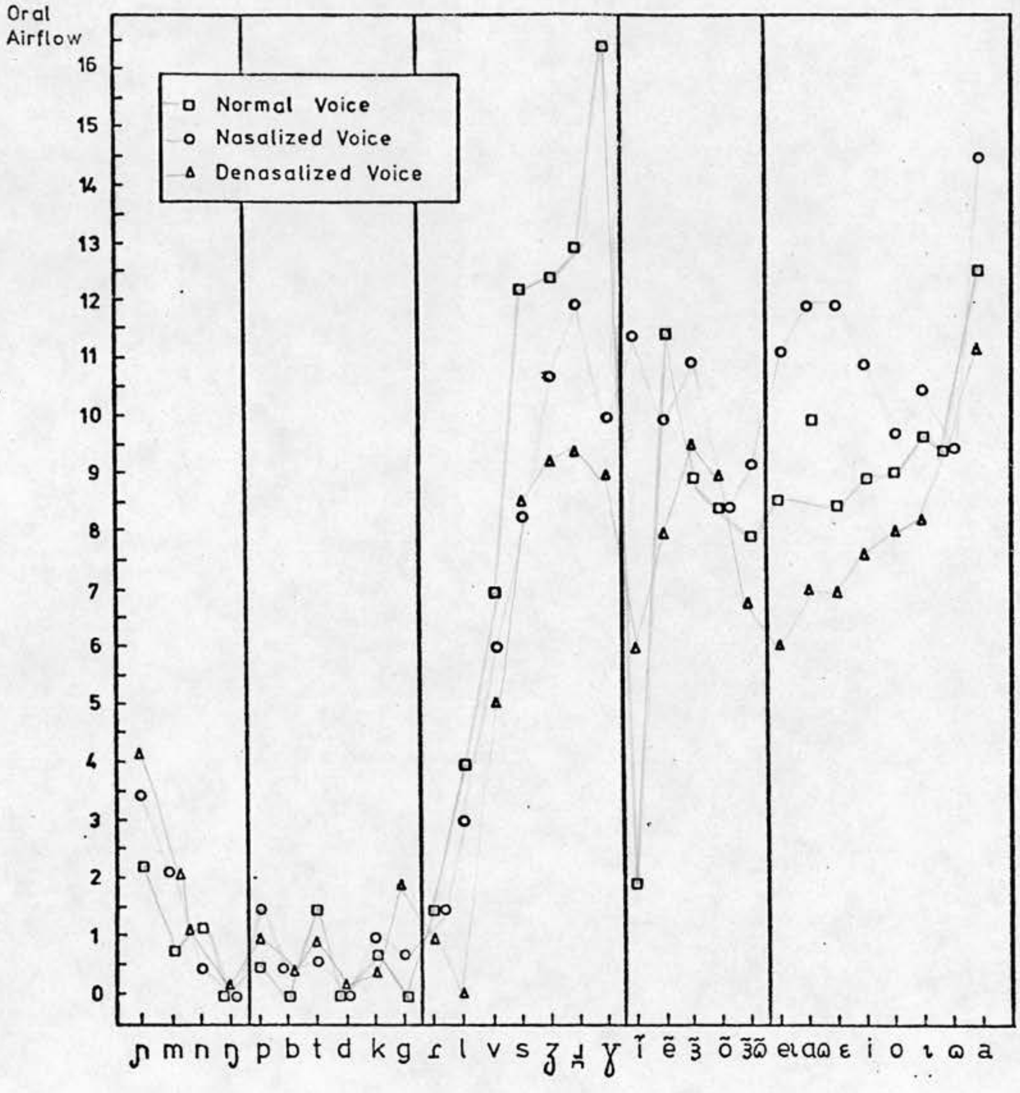


Fig. 28 Distribution of amount of oral airflow in an arbitrary millimetric scale (ordinate) for the segments (abscissa) of a short text uttered with normal, nasalized and denasalized voices.

represents denasalized voice.

The palatal nasal consistently revealed the presence of some airflow from the mouth with a higher level of oral airflow for denasalized voice. In nasalized voice, the oral airflow level was less significant. In all cases of nasal consonants apart from the palatal nasal, and in the case of the stops, the presence of oral airflow was not consistent, and when present, the level was very low. The fricatives and the approximants [ɾ, l, ɹ̯] showed a typical distribution of relative levels of oral airflow: normal voice presented the highest level, nasalized voice presented an intermediate level, and denasalized voice presented the lowest level for all segments. In denasalized voice, the [l] disclosed an extremely low level, touching the baseline and in normal voice, [ɣ]disclosed an extremely high level as one can see in Fig. 28 . In general, the segments which are characterized by a higher degree of friction presented a higher level of oral airflow.

The BP nasalized vowels did not manifest any regular pattern, except for the fact that, in nasalized voice, the nasalized vowels tended to have a greater amount of oral airflow than in normal voice, but the difference was not very much. The BP oral vowels showed a clear distribution of the relative levels of oral airflow: nasalized voice presented the highest levels, normal voice presented intermediate levels, and denasalized voice presented the lowest levels of oral airflow for all oral vowels.

1.3. Conclusions

The method and the experiment discussed above have limitations, which prevent us from arriving at definite conclusions at this time. A more reliable measurement of the aerodynamics is needed and the experiment should be done on a larger scale. However, this preliminary investigation revealed some interesting points.

a) The vowels presented a lower level of nasal airflow than the consonants in nasalized voice.

b) The nasalized vowels presented a small increase in the level of nasal airflow when said with nasalized voice, as did the nasal consonants.

c) The oral airflow level is not dramatically changed when the text is said with nasalized or denasalized voice. However, denasalized voice has a tendency to show up lower levels of oral airflow than the other two voice qualities in the case of linguistically oral consonants and vowels.

d) Normal voice indicate higher levels of oral airflow than the other two voice qualities for all oral consonants; nasalized voice has a tendency to have higher levels of oral airflow than the other two voice qualities for all linguistically oral vowels.

e) Finally, this experiment indicates that linguistically nasalized vowels and nasal consonants have a higher level of nasal airflow in nasalized voice than in normal voice. This finding supports the articulatory function of the velum suggested earlier (Part III, Chapter 5).

Chapter 2 : A Combined Investigation of the Velopharyngeal Mechanism with Fluorographic, Pneumotachographic and Laryngographic Television Recordings

2.1. Introduction

The use of different techniques to record articulatory and acoustic data simultaneously is obviously of great interest to phonetics. Several authors compared the behaviour of the velopharyngeal mechanism with other speech activities. Björk (1961) used tomography and cineradiography synchronized with spectrography. Bell-Berti and Hirose (1975) used a simultaneous fiberoptic and electromyographic approach. Lübker (1968) carried out an electromyographic-cineradiographic investigation of velic movements. Lübker and Moll (1965) made simultaneous oral/nasal airflow measurements and cinefluorographic observations of speech. Warren (1976) recorded the oral/nasal air pressure and oral/nasal airflow as preliminary data for his modified hydrokinetic equation (see Part III, Chapter 2), which provides an estimated area of the nasal port during speech.

We decided to carry out an experiment with the aim of testing the technique for further investigations and collecting simultaneous data about the velopharyngeal mechanism and other articulatory characteristics, using phonetic material from Brazilian Portuguese.

2.2. Material and Method

The recorded phonetic material includes the subject's name (the author of the thesis), the date in English, and the six BP sentences given below:

a) Henrique Cunha sonha que tem um amigo muito doente na cama.

b) Quando é que as mães encontram pães e vinho para comprar?

c) Com os leões não se brinca assim.

d) João viu um homem tão alto com fome no trem.

e) Um olho azul chama atenção.

f) Nenhum submarino atlântico enguiçou.

The translation and the phonemic transcription of these sentences can be seen in Part VI, Chapter 4, Section 4.1. These sentences plus the subject's name constitute the phonetic material of the experiment described in the present chapter, and part of the same material was used in the investigation reported in the next chapter (Part VI, Chapter 3). See samples of the traces in Fig. 29.

The experiment was designed in such a way that the velum movements, the tongue positions, the oral airflow, the nasal airflow, the vibrations of the larynx and the audio signal could be recorded simultaneously for comparison. The recorded data included a cine-fluorographic picture recorded on the lower track of a TV tape, and the airflow, the laryngogram, the audio signal and a time marker registered by a multichannel mingograph on the upper track of the same TV tape. The mingographic traces on the 10" wide paper were picked up by one TV camera. Another TV camera was used to record the X-ray beams from the image intensifier. With the TV recording mixer, both images were monitored separately, then mixed together on a TV tape cassette. The final recording was also controlled by a third TV monitor. The X-ray image was controlled by the radiologist with an independent TV monitor. Fig. 30 shows the block diagram of the apparatus. This experiment provided three different types of recordings: a) the video tape with X-ray pictures, mingographic traces and the sound of the utterances; b) the mingographic print-outs on paper with all the traces; c) a magnetic tape with the laryngographic recording on one channel and the audio signal on the other.

The airflow traces were picked up by two pneumotachographic flowmeters connected to two special pressure transducers producing an output voltage proportional to airflow. Each of the oral and nasal airflow signals were amplified and registered by two channels of the mingograph, one smoothed by a low-pass filter. This technique proved to be very useful and revealed, for example, that during some segments, the airflow from the nose was slightly negative on the filtered trace. It also showed vibratory resonances with reduced

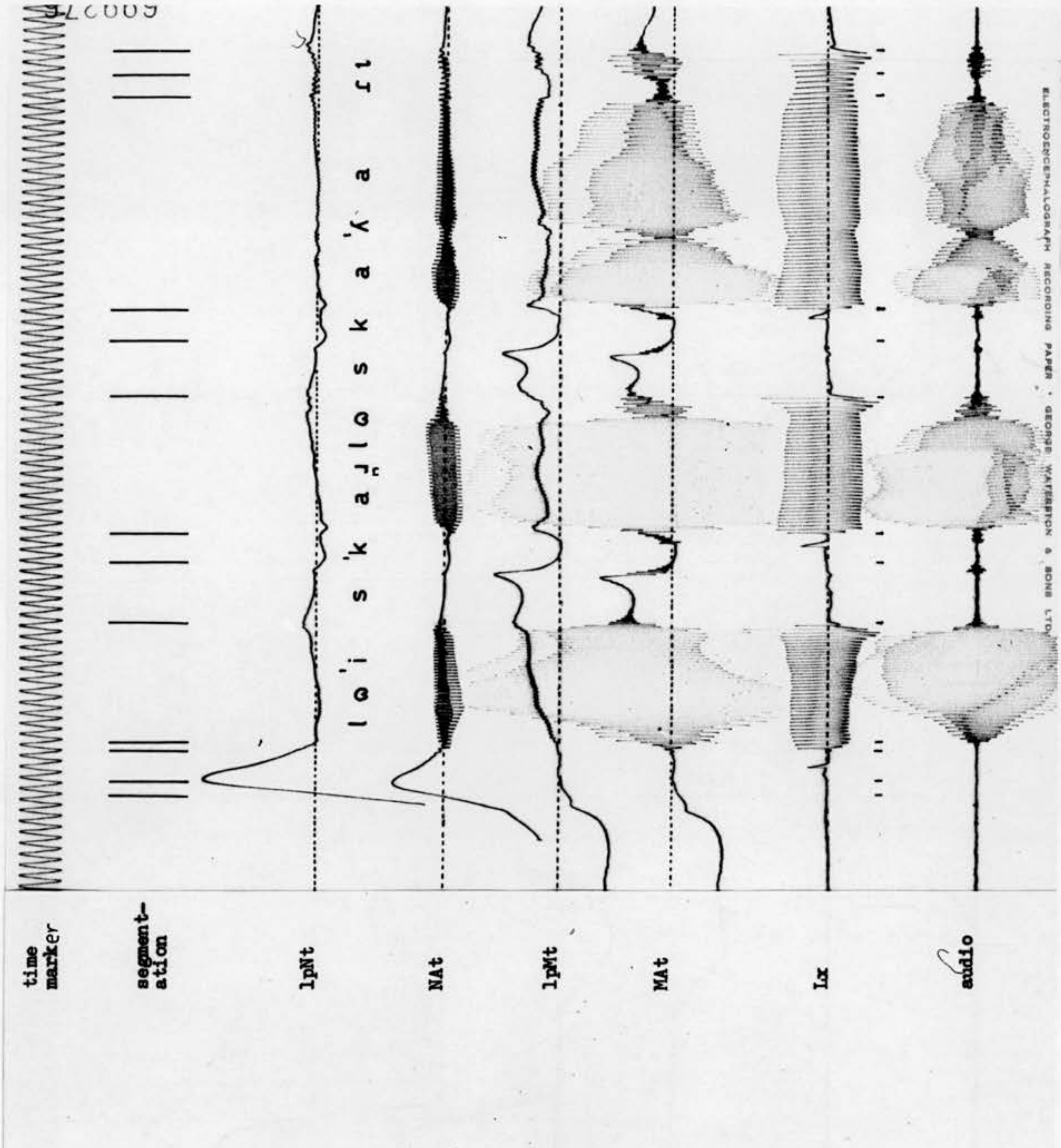
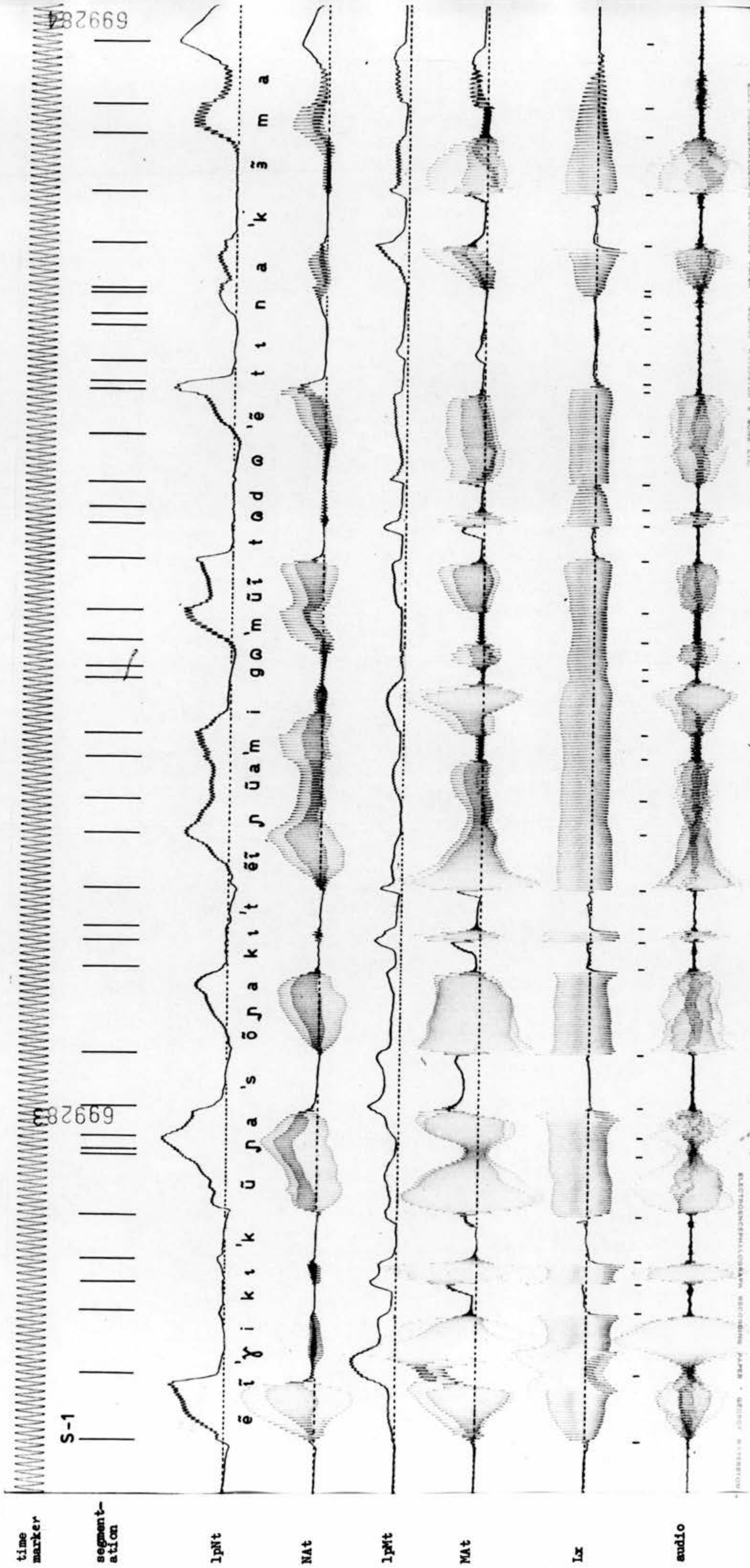


Fig. 29 Samples of Brazilian Portuguese sentences with simultaneous recordings of nasal and oral pneumotachographic traces together with laryngographic, audio signal and time marker displays.


time marker
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lpNt
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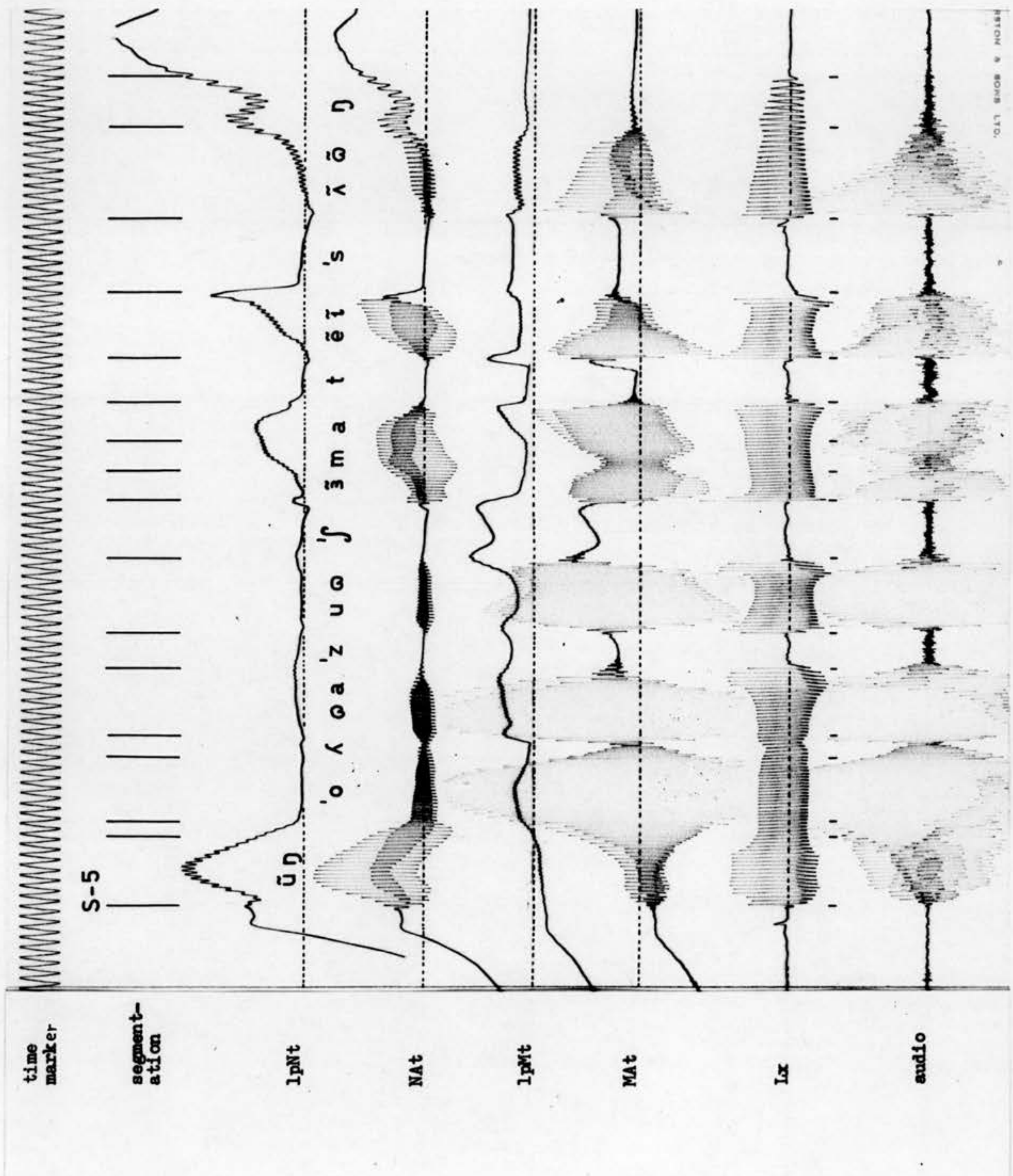
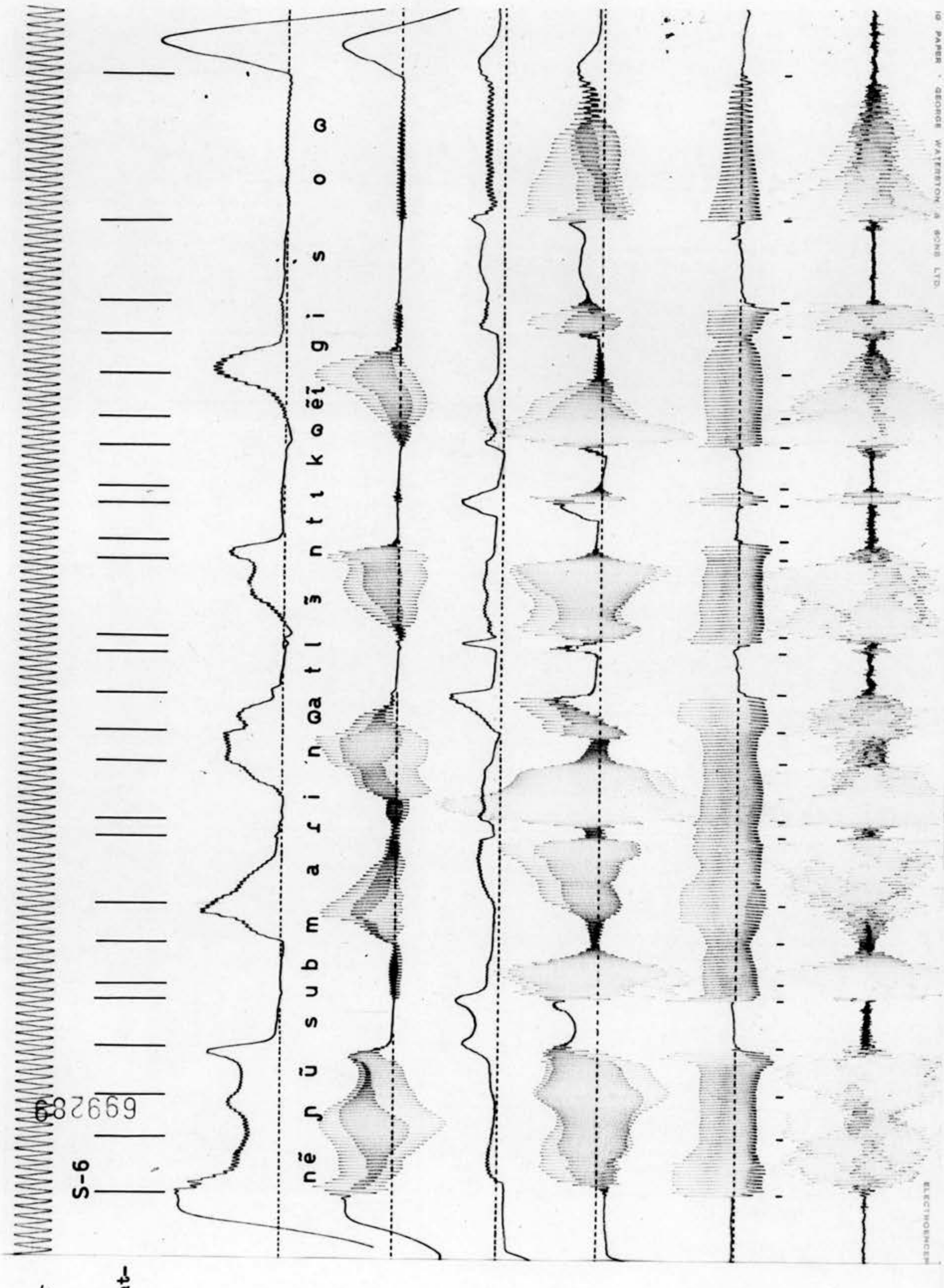

time marker
segmentation
lpNt
NAt
lpMt
MAt
Lx
audio
S-5


time marker
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lpNt
NAt
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MAt
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audio
S-6

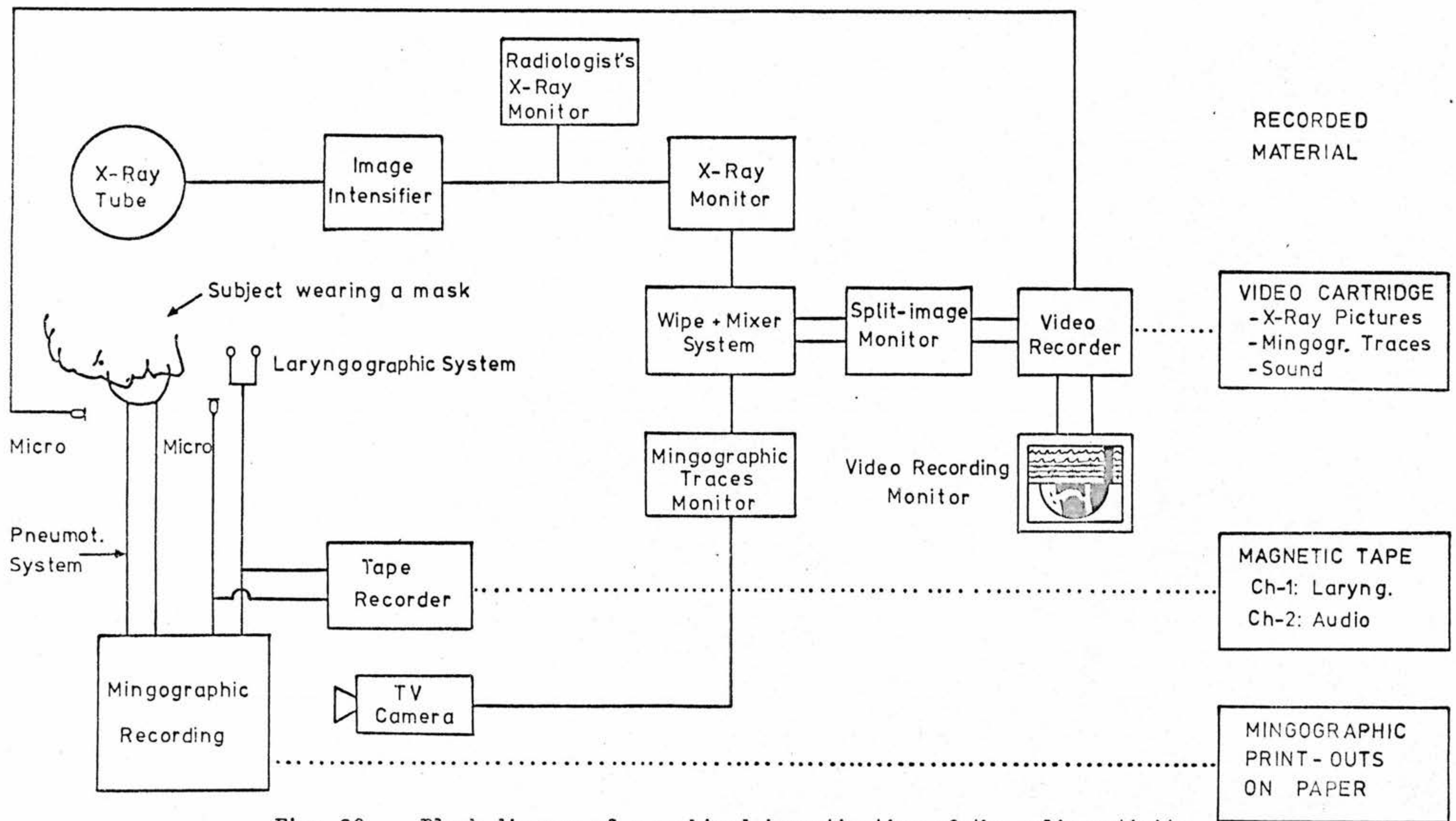


Fig. 30 Block diagram of a combined investigation of the velic activity with cineradiographic, pneumotachographic and laryngographic recordings on a TV tape cassette.

intensity on the unfiltered nasal trace in the case of oral vowels. In all these cases, the filtered trace did not make any excursion from the baseline.

Diagrams from the X-ray pictures can be made by stopping the tape and drawing the configurations on the glass of the screen with a water-ink pen that is easily removed. The traces are then copied on a tracing paper for permanent record.

2.3. Discussion

The TV tape provided an adequate image of the vocal tract in general, that allowed a good observation of the tongue and velic movements. The mingographic traces, however, were not as clear as expected and this caused considerable difficulty in comparing the X-ray pictures with the related point of the mingographic record on the screen. Two main factors contributed to this. First, the definition of the traces on the screen; when the tape is in motion, the definition of the X-ray pictures is reasonably good. One can quite easily follow the movements of the tongue and the velum. After listening to and watching the video tape for same time, it is possible to follow the tongue and velum movements in synchronism with the sound, and this is an excellent way to study the articulatory positions of the tongue and the velum. However, when the tape is stopped and allows inspection of 'frozen' replay, the definition of the traces on the screen is severely degraded, even when a monitor with very small screen is used. The mingographic traces have a worse definition than the X-ray pictures on all occasions. Secondly, synchronization; when an X-ray image appears on the screen, the related point on the mingographic traces is located at the extreme top right corner of the screen, and this makes it impossible to follow both the X-ray, and the mingographic traces by just watching them. The traces are hidden by the ceramic blotter roller of the mingograph and there is therefore a delay before the traces appear. The speed of the paper (10 cm/sec) is not too fast, but the amount of information is too great to be assimilated in detail.

The video tape recorder system used does not allow the tape to be shuttled back and forward easily in order to memorize and compare one display with the other. The mingographic signal takes approximately 0.5 secs to appear at the centre of the screen and this is the delay that would have to be introduced in some way into the X-ray image channel to match the corresponding point on the traces. We have no facilities for doing this at the moment.

One of the aims of the experiment was to provide a way of comparing velic movements with nasal airflow for a given articulation. As explained above, the tape did not provide a satisfactory method, but it did provide useful information about velic movement, tongue position and airflow. It was extremely difficult to study both together on the screen, but they could be observed in a better and easier way if a synchronisation mark was recorded on the mingograph, so that a particular frame of the X-ray image could be easily identified with a position on the paper. When the TV image is held in a fixed position, the researcher could look at the traces on the paper, compare them with the X-ray picture, and make the necessary notes.

It must be pointed out that another drawback of the video playback equipment is that it does not stop the image instantaneously. This makes it difficult to get the required image on the screen. Also, when the equipment is stopped by means of a switch, this often introduces spurious noise across the picture, distorting the image.

2.4. Results

The experiment provided useful information about the activities of the velum and the tongue, and about the vocal tract shape in general. Information was also gained about aerodynamics, and about the laryngeal activity, and material was recorded for further acoustical and auditory analysis. Unfortunately, the TV recording technique system used proved to be useful only when the tape was running. For this reason, the technique is good for a qualitative analysis of the events involved, but it is difficult for use in quantitative studies, because of the great loss in the definition of the traces when the tape is stopped for 'frozen' replay, and because of the impossibility of stopping at the exact point desired.

In spite of these drawbacks, the analysis of the tape revealed interesting facts. I have observed, for example, that when the velum moves up, the middle third of it assumes a bulge shape, giving the impression of muscular tension, but when the velum is down, it has a more regular shape giving the impression that the muscular bulge is dissipated by some sort of muscular relaxation.

The velum assumes a wide range of different positions during speech. The velum is kept higher during nasalized vowels than during nasal consonants, for example. Velic movements, as discussed in more detail in another chapter of the present thesis (Part III, Chapter 5), were clearly shown to have an articulatory function of the same nature as the tongue, the lips and the vocal folds. The velic port does not assume only two positions: one open and the other closed. The velum assumes different positions for different speech segments because of the functional need for controlling nasality precisely.

During speech, the velum moves following an axis in a diagonal line related to the anatomical location of the fibres of the levator and palatoglossus muscles. However, it has been observed that, at the end of speech, when the subject starts to breathe in, the velum, already lowered, undergoes another definite pull downwards, in a direction related to the anatomical location of the fibres of the palatopharyngeus muscle. This finding is illustrated in Fig. 31. A similar vertical movement after a first diagonal lowering of the velum was also observed in the case of some nasal consonants, but with a much reduced action.

In relation to Brazilian Portuguese, special attention was given to tongue positions in relation to articulatory and aerodynamic features. We found that the palatal nasal has in fact a tendency to be retracted, and the unreleased 'velar' nasal has a tendency to be articulated almost at the uvular position. The occurrence of nasals postvocalically in syllables, following a nasalized monophthong or diphthong has been found consistently as described in the present work (see Part I).

Chapter 3 : An Investigation of Nasal and Oral Airflow Levels in Connected Speech

3.1. Introduction

This study is based on the phonetic material used in the investigation reported in the preceding chapter (Part VI, Chapter 2). During the performance of the sentences for the television recordings, the subject was wearing a mask with an internal division to isolate the oral airflow from the nasal airflow. Attached to each chamber, there were two pipes with pneumotachographic transducers (see Part VI, Chapter 2, Section 2.2.). The signal from each transducer was

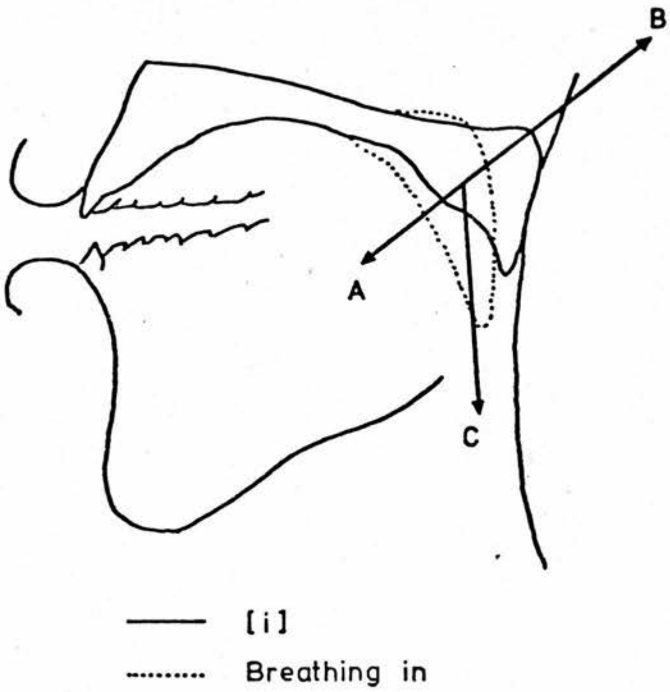


Fig. 31 Diagram from X-ray pictures to illustrate two extreme positions of the velum and the process of lowering the velum. A - B represents the speech axis along which the velum is displaced: C represents a second action upon the velum to bring it further down in the case of respiration and sometime, with a less extensive movement, in the production of nasals.

amplified and produced two mingographic traces on a paper: one representing the direct and amplified signal from the transducer, the second representing the signal from the transducer, amplified and smoothed by a low pass filter.

The low pass filtered signals were used in the present study. Figs. 32 - 34 show the oral (dotted line) and the nasal traces (solid line) superimposed for four Brazilian Portuguese utterances. The thin horizontal line represents the moment when the airflow is zero, i.e., when there is no airflow at all. When the traces make a positive excursion from the baseline, this indicates egressive airflow, and when the traces make a negative excursion from the baseline, they indicate ingressive airflow. The vertical lines represent the best possible phonetic segmentation, taking into account not only the two traces, but the six parameters recorded on the mingographic paper, as described in Part VI, Chapter 4 of this work. The laryngographic trace was used as an important reference for segmenting speech.

The aim of this investigation was to study the relationship between the oral and the nasal airflow in connected speech. The aim of this study is therefore concerned with the aerodynamic aspects of the oral:nasal ratio (see Part III, Chapter 4). The apparatus used in this investigation is sensitive and reliable enough to allow a fairly precise study of the oral and nasal aerodynamics in speech. The calibration of the transducers is given in Figs. 32 - 34, but for the purpose of the present work, we did not use the real calibration, but another calibration in order to produce a less complex list of readings. So, instead of reading the measurements in a scale of 417 ml/sec for nasal airflow and 438 ml/sec for oral airflow, an arbitrary millimetric scale was used for both,

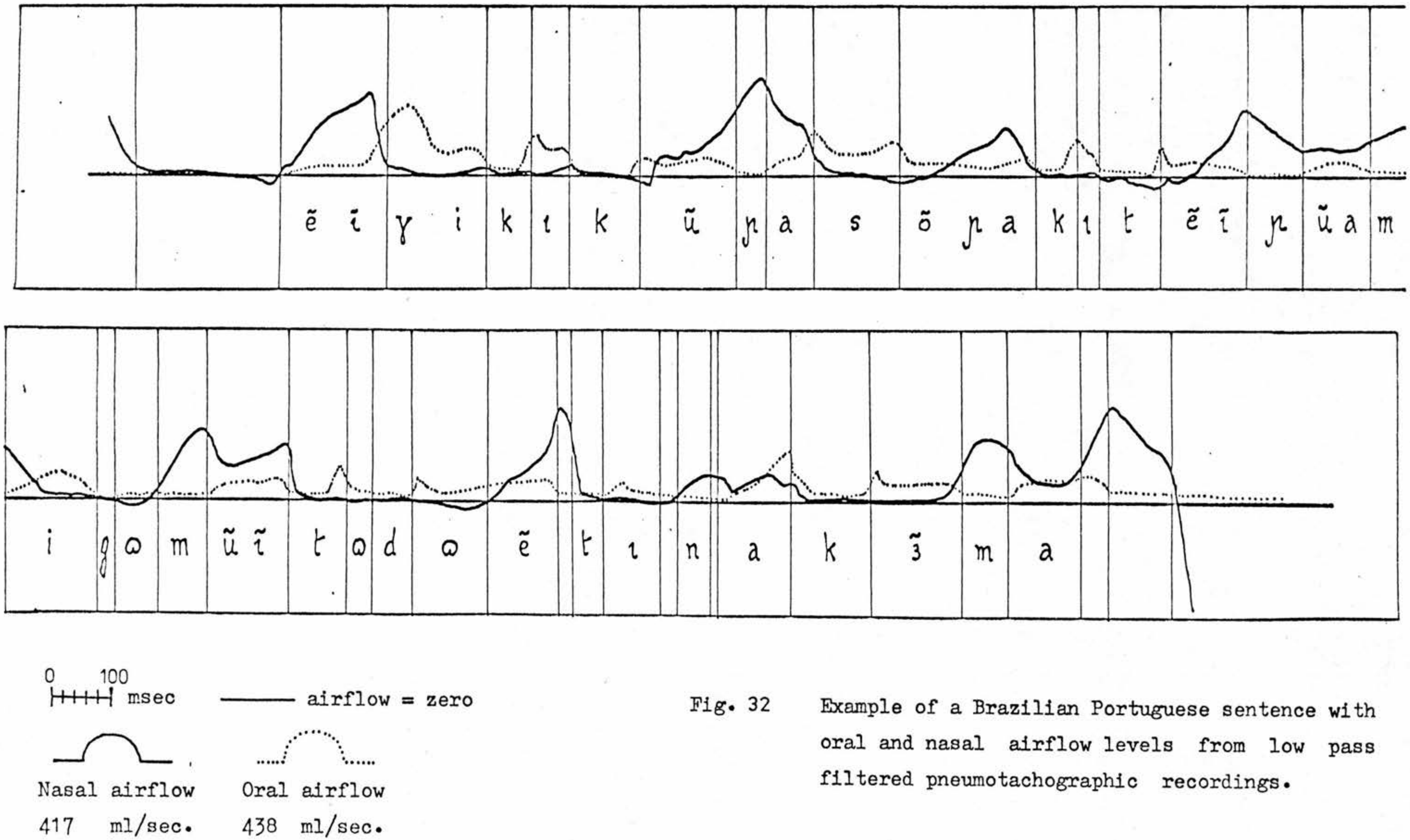


Fig. 32 Example of a Brazilian Portuguese sentence with oral and nasal airflow levels from low pass filtered pneumotachographic recordings.

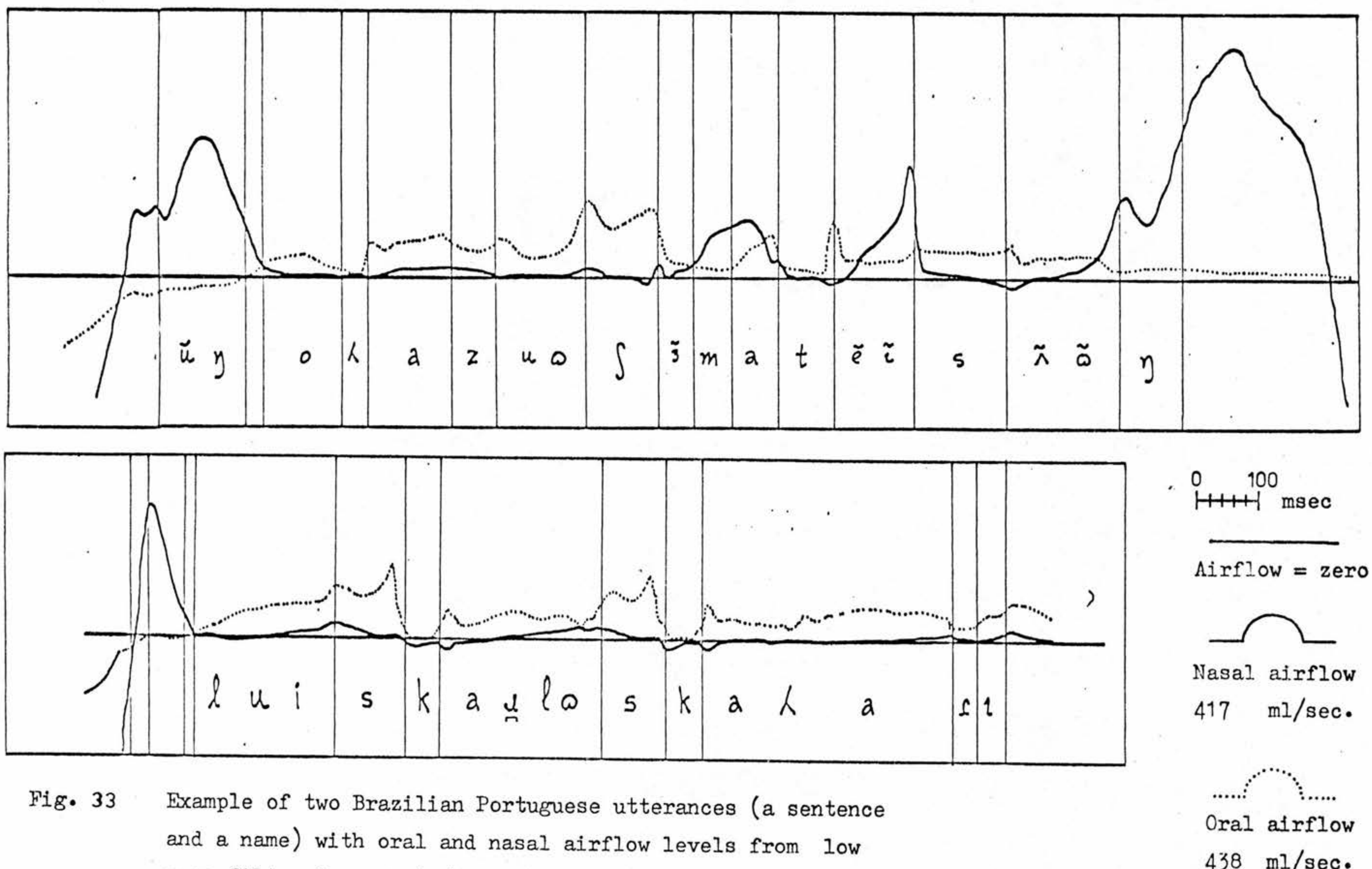


Fig. 33 Example of two Brazilian Portuguese utterances (a sentence and a name) with oral and nasal airflow levels from low pass filtered pneumotachographic recordings.

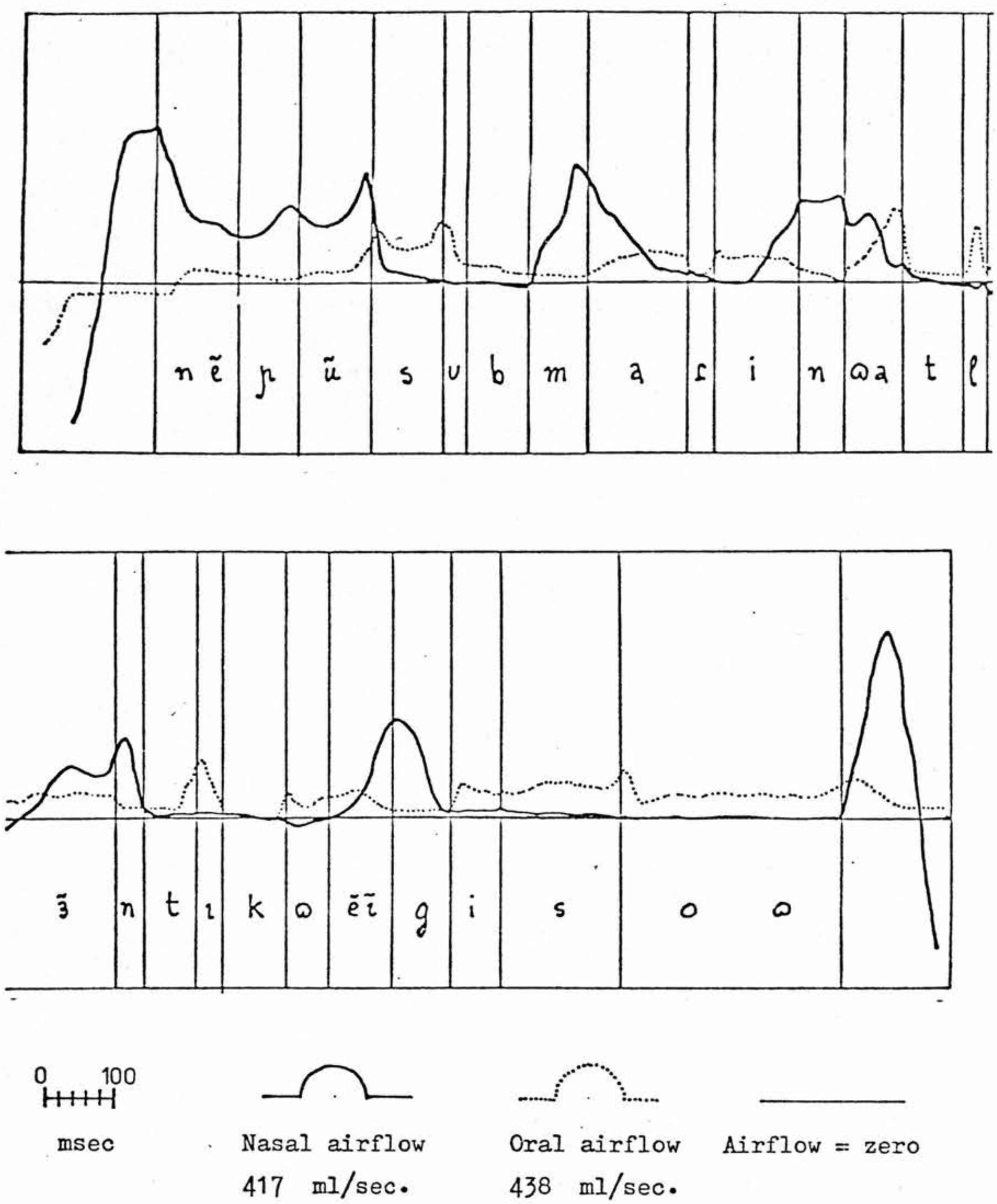


Fig. 34 Example of a Brazilian Portuguese sentence with oral and nasal airflow levels from low pass filtered pneumotachographic recordings.

using the horizontal baseline as zero. The readings were computed by measuring the distance from the baseline to the oral and nasal airflow traces. The amount of airflow was then read at the exact moment when a segmentation vertical line occurred, and at a selected point around the center of the phonetic segments.

All readings are displayed on graphs in Figs. 35, 36 where we have the oral airflow scale in millimetres, on the ordinate, and the nasal airflow scale in millimetres, on the abscissa. All negative numbers stand for ingressive airflow and all positive numbers stand for egressive airflow. x represents the readings from Fig. 32 ● represents the readings from Fig. 33 ; ■ represents the readings from Fig. 34 . Fig. 35 refers to readings taken at the centre of the phonetic elements as specified in the Figs. 32 - 34. Fig. 36 refers to readings taken at each vertical (segmental) line as shown in Figs. 32 - 34 . The most interesting findings are discussed below.

3.2. Oral and Nasal Airflow Distribution Related to Readings Made at the Centre of Phonetic Segments

The segments present a typical distribution in Fig. 35 As one can see, the nasal consonants occupy the right bottom (I) area, showing that they have a high level of nasal airflow and a very low level, if any, of oral airflow. Nasalized vowels are located just above the nasal consonants (II), showing that they have high level of nasal airflow and a significant concomitant level of oral airflow. The vowel [a] is the most open vowel used and it presents the highest levels of nasal and oral airflow. When this vowel is oral, it tends to have a low nasal airfow level, although it always revealed some nasal airflow level (III), and when it is nasalized, this vowel tends to have a lower oral airflow level than the corresponding oral

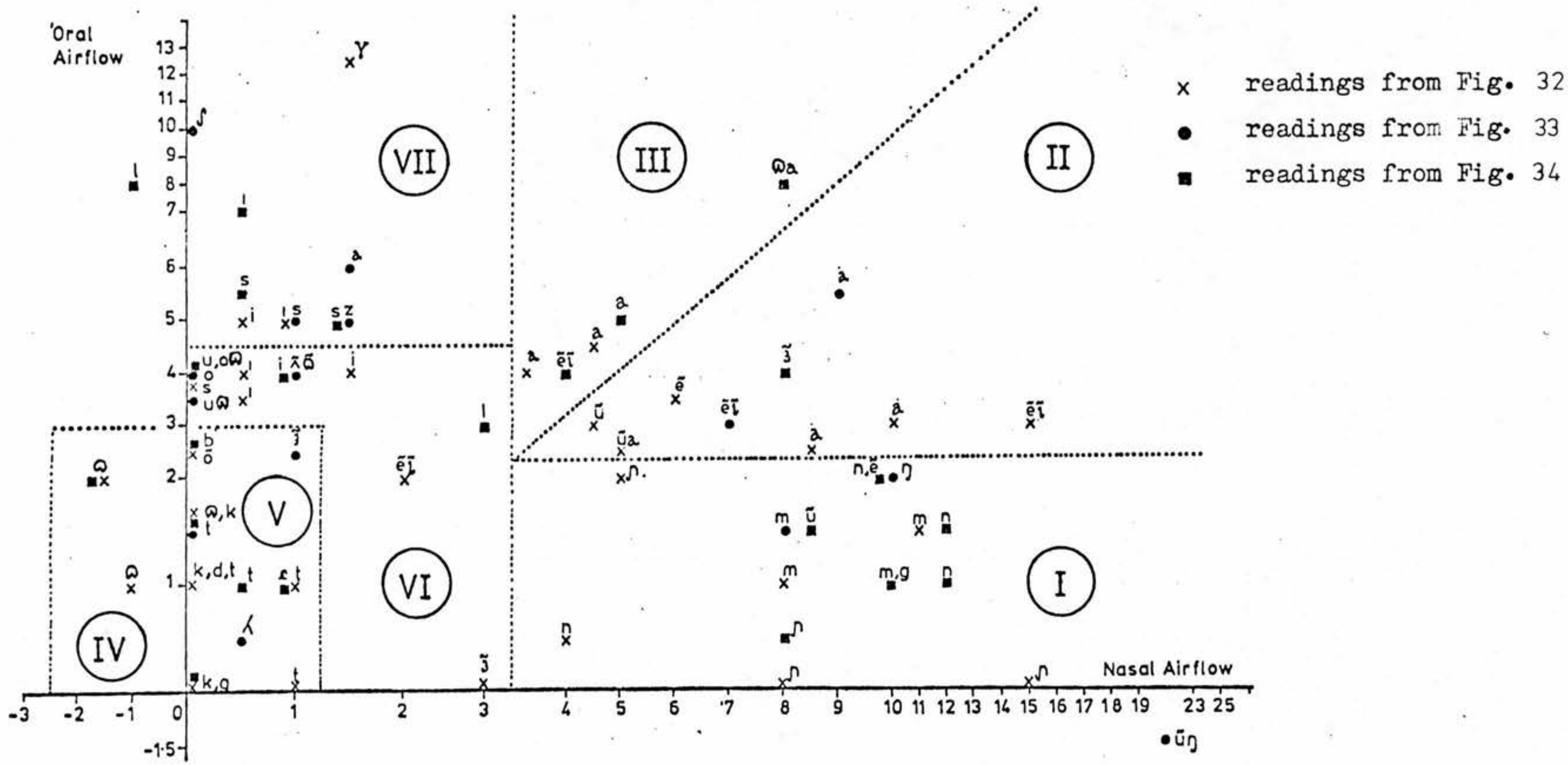


Fig. 35 Distribution of oral (ordinate) and nasal (abscissa) airflow levels in an arbitrary millimetric scale, taken at the centre of phonetic segments. Positive numbers refer to egressive airflow and negative numbers refer to ingressive airflow

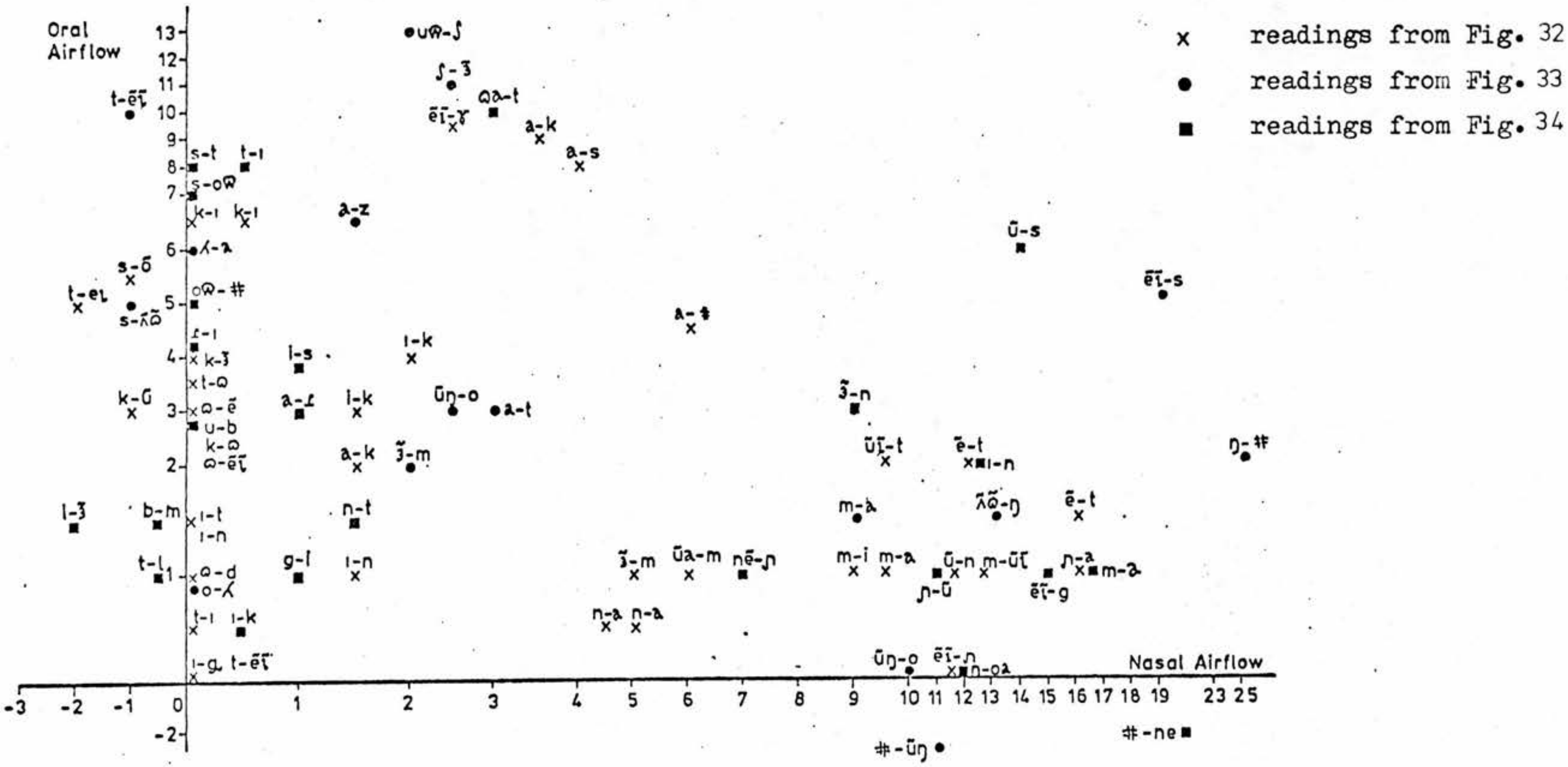


Fig. 36 Distribution of oral (ordinate) and nasal (abscissa) airflow levels in an arbitrary millimetric scale, taken at the segmentation lines, specified by the preceding and following segments. Positive numbers refer to egressive airflow and negative numbers refer to ingressive airflow.

realization. There is a clear tendency for close vowels to have a lower nasal airflow level than for open vowels (VI). The stops are concentrated around the oral and nasal zero values (V). They tend to have a small amount of oral airflow more often than a small amount of nasal airflow. The close back oral vowels manifest not only a clear tendency to have no nasal airflow at all when auditorily oral, but also a small amount of ingressive nasal airflow (IV). Surprisingly, the fricatives [s, z, ɣ, ʃ] revealed some small amount of nasal airflow together with a very high level of oral airflow (VII).

We could sum up the results presented in Fig. 35 by building two scales of values, one setting up values ranging from the segments with higher level of nasal airflow to the segments with lower levels, and another ranging from segments with the highest oral airflow levels to the segments with the lowest oral airflow levels:

Scale of segments with decreasing nasal airflow levels:

1. nasal consonants
2. nasalized vowels
3. oral open vowels
4. oral close front vowels
5. stops and fricatives
6. oral close back vowels

Scale of segments with decreasing oral airflow levels:

1. fricatives
2. oral close front vowels
3. oral open vowels
4. nasalized vowels
5. oral close back vowels
6. nasal consonants
7. stops

3.3. Oral and Nasal Airflow Distribution Related to Readings Made at the Boundaries of Two Phonetic Segments

Although there is not a very consistent and typical distribution of the phonetic segments, nevertheless a few tendencies showed up clearly. First of all, it must be noted that this type of reading does not present very consistent and typical patterns because the phonetic parameters tend to change more rapidly at the segmental bondaries.

The boundary preceded by a nasal consonant and followed by an oral or nasalized vowel revealed a tendency to be grouped together with the nasal consonants, at the bottom right area of the graph (see Fig. 36). The boundary preceded by a vowel and followed by a nasal consonant presented a much lower nasal airflow level than the boundary preceded by a nasal and followed by a vowel. This fact clearly shows the tendency in connected speech to nasalize a vowel following a nasal, and to nasalize the vowel preceding a nasal to a lesser extent.

The reading characterized by a nasalized vowel plus a stop revealed a high level of nasal airflow and a relatively small level of oral airflow. It is interesting to see that the oral airflow level, in this case, is higher than the level typical of nasal consonants. The auditorily perceived phonetic realization of a nasal consonant between a nasalized vowel and a stop was treated as an individual segment, but in cases where no clear nasal consonant was perceived, at the boundary of the two segments, the adjusting articulatory changes did not in fact reveal an airflow typical of nasal consonants. But, the oral/nasal airflow levels at that point were also different from the expected levels of a nasalized vowel.

Surprisingly, the boundary of a vowel followed by a voiceless velar stop revealed the presence of a certain amount of nasal airflow together with very high oral airflow level.

The boundary of a stop and a nasalized (or oral) vowel did not manifest any nasal airflow at all. Nasal airflow started with the vowel onset and usually increased towards the end of the nasalized vowel. The only case of an oral vowel followed by a nasalized vowel showed that the nasal airflow started at the mid point of the combined segments, assumed to be the best phonetic boundary between the two segments.

Nasalized vowels at the end of a sentence tend to combine a very high level of oral and nasal airflow.

The boundary between a nasalized vowel and a fricative revealed a very high oral airflow level and a low nasal airflow level. Because of the high level of oral airflow and the presence of friction, the low level of nasal airflow is probably not sufficient for the fricative to be perceived as having even a slightly nasalized beginning.

3.4. Oral and Nasal Airflow Distribution Associated with the Period Immediately Preceding the Beginning of the Utterances

In Figs. 32, 33 and 34, one utterance started with a nasal, another utterance started with a dentialveolar lateral, and two utterances started with a nasalized vowel. The sentence in Fig. 32 was articulated after the subject had breathed in, and out, so that before the nasalized vowel, there was a period of zero airflow. Just immediately before the beginning of the nasalized vowel, the nasal trace had a very small ingressive level for a short moment. This could be due to the lowering of the velum rarifying the air inside the nose a little.

The first sentence in Fig. 33 was articulated after the subject had breathed in and almost instantaneously after the subject started to breath out. There was a very short period of steady airflow after which the nasalized vowel started with increasing nasal airflow level. In this example, when [uŋ] was heard, the oral traces were slightly below the baseline indicating an ingressive airflow.

In Fig. 34 the sentence started with a nasal consonant. The nasal airflow reached a very high level before the beginning of the dentialveolar nasal, and immediately changed to a lower level during the articulation of the following nasal segments. The nasal airflow increased rapidly from the position of breathing in, without any interruption or steady level. The oral airflow is still ingressive when the nasal consonant started, but immediately it became egressive.

In Fig. 33 the second utterance is a name and it started with a lateral sound. This utterance was the first of a group of sentences and was preceded by a short period of inspiration, followed by a very rapid and brief period of expiration. Nasal airflow is controlled in such a way that at the beginning of the lateral, the nasal airflow level is zero. The oral airflow assumed a zero position well before the beginning of the lateral.

Finally, it can be said that, in general, oral airflow needs more time to be controlled before the onset of the speech sounds than the nasal airflow. Nasal airflow is sometimes cut almost instantaneously to interact in synchronism with the phonetic demands of the segments which begin the sentences.

3.5. Oral and Nasal Airflow Distribution of an Utterance Without Any Nasal Consonant or Any Nasalized Vowel

In Fig. 33 the second utterance does not have any nasal phoneme or nasalized exponents. However, a glance at the nasal trace shows that the level is not maintained constantly at zero, but for short periods of time it shows a low level of either egressive or or ingressive nasal airflow. The most noticeable egressive nasal airflow occurred at the boundary between [i] and [s], during [lɷ] and at the end of [ʎa]. After the release of [k] (2 times), and at the end of [s] (2 times) preceding the [k], there was a moment of low ingressive nasal airflow. The occurrence of ingressive nasal airflow is linked to segmental boundaries, especially boundaries involving voiceless fricatives, voiceless stops and [ɷ]. This last remark is also applicable to other utterances which were investigated.

3. 6. Conclusions

It has been observed in all the sentences investigated that a vowel following a nasal consonant is partially nasalized and has a decreasing amount of nasal airflow. The end of the vowel is completely oral and the nasal airflow level is at the baseline. This may be the reason why speakers do not recognize such vowels as nasalized.

As far as nasality can be related to nasal airflow, it can be said that segments are fully characterized auditorily in Brazilian Portuguese before the third part of the duration of the segments. For example, a nasal will have its target (with higher nasal peak and lower oral airflow level) around the second third of its duration. A nasalized vowel is fully characterized at this point as well, where the highest nasal level and a higher oral level of airflow occurs. The same applies to the oral vowels principally when next to a nasal or nasalized vowel. At around two thirds of their duration, the nasal airflow will be practically zero and the oral airflow level will be very high.

In the sentences investigated, there was no accumulation of similar segments sharing exactly the same oral/nasal airflow values. This is obvious if one looks at the Figs. 35, 36. Although there was a tendency for some segments to occupy a certain area in the graph, nevertheless airflow in connected speech is constantly fluctuating, due mainly to the changing context such that only rarely do two phonetic segments occur with exactly the same values for the airflow levels, even when two segments are of the same phonetic quality.

Finally, Figs. 35, 36 indicate that some categories of phonetic segments tend to occupy specific areas on the chart of the distribution of oral/nasal airflow. This fact corroborates the suggestion made earlier that the velum assumes different articulatory positions following a preset pattern for normal connected speech (see Part III, Chapter 5).

Chapter 4 : A Pneumotachographic Investigation of Nasality in Brazilian Portuguese

4.1. Introduction

The aim of the present investigation was to study instrumentally the recording of different parameters of speech recorded simultaneously, in order to support or to refute the phonetic description of nasality in BP given in Part I of the present thesis. Special sentences with selected words were prepared for the recordings, containing a representative number of possible occurrences of nasality in Brazilian Portuguese.

4.2. Method and Material

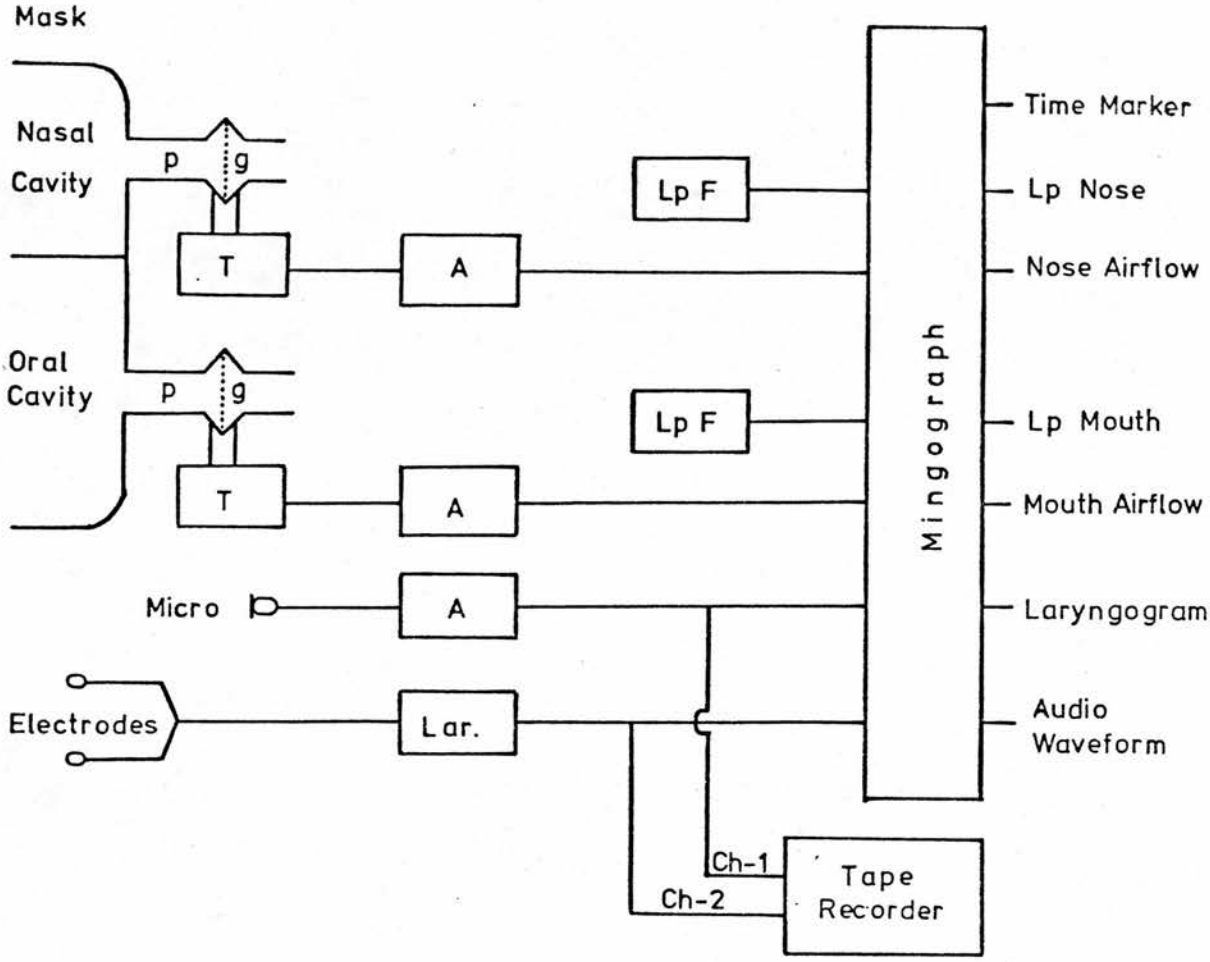
The experimental set-up used in this investigation was designed by Mr. J.K.F. Anthony in the Department of Linguistics at the

University of Edinburgh. It is different in many respects from electrokymography using the Aerometer (see Part IV, Chapter 1, Section 1.3., and Part VI, Chapters 1, 2 and 3). A simplified block diagram of the system is given in Fig. 37.

The airflow from the nose and the mouth is separately conducted through two small pipes fixed externally to an anaesthetic mask. A gauze is fixed across the centre of each pipe, acting as a resistance to the airflow. With the help of a special transducer which picks up the airflow differential at two points, one in front of the gauze, and the other behind it, it is possible to measure how much air is flowing through the pipe. The transducer transforms flow into pressure, and pressure into voltage variation. The signal from the transducer goes to an amplification system, and then one line goes directly to the mingograph, while a shunt line goes to a low-pass filter system, and thereafter to the mingograph. The low-pass filter removes high frequencies and partially smoothes the signal from the transducer to provide a line on the traces reflecting intensity variations.

The trace of the unfiltered signal from the transducer is labelled Nose or Mouth Airflow trace (NAt and MAt); the trace of the filtered signal is labelled Low-pass Nose trace (LpNt) and Low-pass Mouth trace (LpMt) (see Fig. 29 in Part VI, Chapter 2).

A microphone placed in front of the mask, near the mouth pipe, was used to record the audio signal. This signal is amplified and connected to the mingograph to provide the audio waveform. The audio signal is also recorded on channel 1 of a tape recorder. Because of the muffling effect of the mask and the location of the microphone, the quality of the recording was not good, sounding somewhat denasalized. However, the tape recording enables one to hear the



p = Pipe
g = Gauze
T = Transducer
A = Amplification
Lar = Laryngograph
Lp F = Low pass filter

Fig. 37 Block diagram of a special kymographic set-up to investigate the aerodynamics of speech.

utterances as many times as one likes and to assist in the analysis of the traces.

A laryngograph was used to record the variation in the electrical impedance when the vocal cords vibrate, by means of two electrodes placed on the front of the neck at the location of the thyroid cartilage. The signal from these electrodes feeds through the laryngograph to the mingograph, and is also recorded on the second channel of the tape recorder.

The signals are simultaneously fed into a mingographic system, together with a time marker (waveform with 50 cps). The mingograph gives a print-out on a moving paper. Each of the sentences used for the investigation were recorded at two paper speeds, at 10 cm/sec and at 25 cm/sec. The calibration of the airflow transducer was as follows: mouth transducer = 458 ml/sec/cm; nose transducer = 450 ml/sec/cm (for more information about the pneumotachographic technique, see Part VI, Chapter 1, Section 1.1.).

The sentences selected for investigation were the same as those used in the investigation described in Part VI, Chapter 2. The subject of the present investigation was the author. The sentences are given below:

1. <u>Henrique Cunha sonha que tem um amigo muito doente na cama</u>.
   (Henrique Cunha dreams he has a friend badly ill in bed)
   /eN'xiki 'kuɲa 'soɲa ki 'teN uN a'migu 'muiNtu do'eNti na 'kama/
2. <u>Quando é que as mães encontram pães e vinho para comprar</u>?
   (When will the mothers find bread and wine to buy?)
   /'kuaNdu 'ɛ ki as 'maiNs eN'koNtrauN 'paiNs i 'viɲu para koN'prax/
3. <u>Com os leões não se brinca assim</u>.

(We don't play like that with lions)

/koN us le'oiNs 'nauN si 'briNka a'siN/

4. Joa͂o viu um homem ta͂o alto com fome no trem.

(John saw a tall hungry man in the train)

/ʒ o'auN 'viu uN 'ɔmeN 'tauN 'autu koN 'fɔmi nu 'treN/

5. Um olho azul chama atenção.

(Blue eyes attract attention)

/uN 'oʎu a'zuu 'ʃama ateN'sauN/

6. Nenhum submarino atlântico enguiçou.

(Not a single Atlantic submarine broke down)

/ne'ɲuN subma'rinu a'tlaNtiku eNgi'sou/

In this investigation, the analysis was based on a second set of recordings of the utterances used in the experiment reported earlier (Part VI, Chapter 2). In Part VI, Chapter 2, Fig. 29 shows samples from the first set of recordings. However, the degree of similarity between the first and second sets of recordings was very striking. There were small variations between the two sets of data in the duration of segments, nevertheless, the general patterns of the traces on both sets of recordings were strikingly similar. For this reason, samples of the second recording are not presented here.

4.3. Analysis of the Traces

The traces for voiceless stops and fricatives do not show any vibrations on the Nose Airflow trace (NAt), though their beginning usually coincides with the return to the baseline of the excursion of the recording on the Low-pass Nose trace (LpNt) when they follow a nasal consonant or a nasalized segment.

For phonetically nasalized vowels, there are very strong vibrations on NAt, and LpNt makes a positive excursion from the baseline. All vowels which are phonetically oral vowels, revealed the presence of some vibrations on the NAt, but in all cases, the LpNt remains at the baseline. The intensity of these vibrations on the NAt for oral vowels are variable and normally weak. Comparing the NAt recordings of a number of vowels, we see vibrations which are moderate in intensity in words like viu (S-4, i.e., in sentence number 4) and in azul (S-5); stronger vibrations are found in the first vowel of chama (S-5) and in the first /u/ of submarino (S-6) than in /aN/ of atlântico (S-6) or in the second /a/ of chama (S-5); in para (S-2), both vowels have very weak vibrations on the NAt.

It is a rule rather than an exception that when a phonetically nasalized vowel is followed by a stop or a fricative, there is a peak on LpNt located on the boundary between the vowel and the oral consonant, the trace dropping steeply just after the onset of the oral segment. On the NAt, there is no vibration at this point and the excursion returns steeply to the baseline. The segmentation in these cases is difficult because of the possibility of a nasal occurring ~~a nasal~~ between the nasalized vowel and the stop or fricative. This pattern was found, for example, in Hen-rique (S-1) (i.e., between /eN/ and /xi/ in that word), nenhum - submarino (S-6). In com - fome (S-4), the NAt peak coincides with the point in time when the vocal cords vibration stops. The excursion decreases for 60 msec until it returns to the baseline. The fricative is about 140 msec long. When the non-nasal consonant is voiceless, there is no recorded signal on the audio trace. In the word aten-ção (S-5), the excursion on the mouth traces do not go down, but continues at a fairly constant and positive level throughout the nasalized vowel and fricative.

Before a stop or a fricative, the MAt of a phonetically nasalized vowel shows a reduction in the intensity of the vibrations, but on the LpMt, the excursion from the baseline increases. This increase of airflow is caused by a constriction in the mouth for the fricative or stop.

Very weak vibrations occur for a very short period of time on the audio trace, between nasalized vowels and stops. These vibrations which occur during the oral closure on the MAt, are certainly not sufficient to characterize a homorganic nasal between the nasalized vowel and the stop, because of the very short duration of its occurrence.

In some cases, like mui-to, sonha - que - tem, Cunha - sonha (S-1), homem - tão (S-4), atlân-tico (S-6), the laryngogram shows vibrations for a short period (around 10 msec) when the corresponding oscillations on the other traces have already stopped and excursions have returned to zero. There are also very weak vibrations on the audio signal for this period of time. This delay in the vocal cord vibrations did not happen, for example, in Henri-que - Cunha, na cama (S-1), al-to, no - trem, com - fome (S-4); in the latter cases, the activity on the nasal traces is synchronized with the vibrations on the laryngogram and both stopped simultaneously.

All nasalized vowels which are represented phonemically by an oral vowel plus a nasal archiphoneme, have a positive excursion on the nasal airflow traces throughout the entire segment suggesting that they are fully nasalized. The airflow in this case has generally a higher level than in the case of nasalized vowels which are not represented phonemically by an oral vowel plus a nasal archiphoneme. Compare, for instance, /e/ and /uN/ in nenhum (S-6), /uN/ in um and /a/ in chama (S-5), /uN/ in um and /ɔ/ in homem (S-4).

The vowels which are nasalized due to the context of a nasal phoneme, present reduced nasal airflow level at their beginning and ending parts, depending on the position of the nasal phoneme. The reduced nasal airflow level occurs during that part of the vowel which is not preceded or followed by the nasal phoneme. For instance, in the word cama (S-1), the first vowel begins with a reduced nasal airflow level, and the second vowel ends with a reduced nasal airflow level. When there is a vowel plus a nasal phoneme plus another vowel, the second vowel presents a mirror image of the first vowel in respect to nasal airflow. The first vowel has an increasing excursion on NAt and on LpNt. The second vowel has a decreasing excursion on LpNt and a reduction of the vibrations on NAt.

In the context of a vowel preceding a nasal, there are three distinct realisations: first, the vowel has nasal airflow throughout its entire duration, as in Cunha (S-1). The first vowel of homem (S-4) is also fully nasalized and the nasal airflow has a positive and level excursion from the baseline. Notice that this vowel is preceded by another nasalized vowel and followed by a bilabial nasal, so that, in fact, the whole word homem is nasalized. Secondly, the vowel starts without a positive level of nasal airflow, with the nasal airflow being added a few milleseconds after the vocalic onset; occasionally, the nasal airflow is added from the middle of the vowel onwards, if the vowel is preceded by a non-nasal segment, as in cama, tem (S-1), submarino (S-6). In the last example, during the first 45 msec out of the total 120 msec, the vowel showed very weak vibrations on the NAt. The LpNt is flat at the baseline. After 45 msec, nasal airflow is added with an increasing level. Thirdly, the vowel is realized without any nasal airflow at all, as in fome , trem (S-4).

A vowel following a nasal consonant shows some nasal airflow for a short duration, which can be as long as half of the duration of the vowel, as in amigo (S-1), no (S-4), submarino (S-6). The nasalization of these vowels is characterized by a damping of the vibrations on NAt, and a more gradual downwards slope of the excursion on LpNt.

The diphthongs /ui/ in muito (S-1), /ua/ in quando (S-2), /ai/ in pães (S-2), /au/ in tão (S-4) and in atenção (S-5), all presented an oral onset, with no excursion of the nasal airflow from the baseline during their beginning. In the word tão (S-4), the oral onset lasts about 40 msec, and the entire diphthong is about 240 msec long. Diphthongs normally have a duration equal to the duration of a stressed monophthong.

In cases of hiatus, as in do-ente (S-1), le-ões (S-3) and Jo-ão (S-4), the nasal airflow starts a positive excursion from the baseline at about half of the duration of the stretch of speech where the two vowels are located. This suggests that the first vowel is predominantly oral and the second is predominantly nasalized.

In relation to the discussion as to whether a homorganic nasal is present or not between a nasalized vowel and a consonant, there was a great deal of variation, but the occurrence of a nasal consonant in this context was not typical. In the few cases, where a nasal consonant could be identified, the nasal consonant was very short compared with the surrounding segments and revealed a dramatic reduction in the intensity of the audio waveform trace. The peak of the airflow on LpNt typically occurs around the boundary between the preceding nasalized vowel and the brief nasal, and the slope of the excursion decreases rapidly. In the NAt, the vibrations are damped; on the laryngogram, the vocal cords are still vibrating, and the LpMt is flat on the baseline. Examples of such segments occur in the words: doente (S-1), encontram, comprar (S-2), brinca (S-3), enguiçou (S-6). In all the other cases where a homorganic nasal might have been expected, in fact, no nasal occurred at all. Examples of words containing no homorganic nasals are: Henrique, muito (S-1) mães, pães (S-2), leões (S-3), atenção (S-5). In all these cases, the LpMt did not return to the baseline, as it normally would for nasal consonants. In the case of atlântico (S-6), when the vocal cords were still vibrating and the LpNt had a peak at the boundary between /aN/ and /t/, the MAt decreased rapidly showing that some sort of occlusion had taken place in the mouth. This stretch of speech lasted for approximately 20 msec, the nasalized vowel lasted for 120 msec and the stop for 80 msec. The audio signal was drastically reduced from the beginning of the decreasing movement of the MAt. These 20 msec of speech, with practically no audio intensity, were not enough to characterize a nasal consonant between the nasalized vowel and the stop, and should be regarded simply as a transitional movement between the two segments.

In encontram - pães (S-2), the excursion on the LpMt goes down to the baseline for a few milliseconds before the end of the vibrations of the vocal cords and the end of the airflow escape. This piece of speech is in all respects similar to the homorganic nasals referred to earlier. Identical cases can be found in João - viu and homem - tão (S-4). In com - fome (S-4), the nasalized vowel showed a very flat and low LpMt, as if a long nasal had occurred before the labiodental fricative. It is interesting to note that, working with informants, I found that some of them consistently pronounced the word um as a syllabic velar nasal, even in isolation; a clear nasal with long duration can also be seen in um - olho.

The presence of nasal consonants making a liaison between two words, when the first word ends phonemically with a nasal archiphoneme and the following word begins with a vowel, was also investigated. The results are as follows: in general, no nasal is present under these circumstances. This fact is exemplified by the LpMt which does not go down to the baseline, as would be expected if an occlusion took place in the mouth blocking the airflow. Some examples are: <u>um - amigo</u> (S-1), <u>com - os</u> (S-3), <u>um - homem</u>, <u>tão - alto</u> (S-4).

Before a pause, at the end of sentences, the words <u>assim</u> (S-3), <u>trem</u> (S-4) and <u>atenção</u> (S-5) showed the presence of an unreleased nasal. The LpMt returns to the baseline, while the other traces are still showing that air is flowing out of the nose, and the vocal cords are vibrating. The LpMt does not leave the baseline again indicating that the nasal is unreleased. The audio signal gradually fades away.

4.4. <u>Additional Observations on the Traces</u>

At the beginning of the utterances, the onset of nasal airflow, marked by a positive excursion from the baseline, is usually in synchrony with the onset of vibrations of the vocal cords on the laryngogram.

Most of the time, the amount of airflow shown on the MAt is in an inverse proportion to the amount of airflow on the NAt. But this correlation is neither absolute, nor necessary. Nasals, however, usually have higher peak on LpNt than nasalized vowels.

The voiced stops and nasal consonants show weak vibrations on MAt during the corresponding period of occlusion displayed on the LpMt. This means that, in spite of the complete blockage of the airflow in the mouth, there are still some oral resonances travelling out of the mouth. This may explain irregularities in the distribution of poles and zeros found in the spectra of nasals.

The nasal consonants show stronger vibrations on the NAt than on the MAt. The nasalized vowels present an almost even intensity level on both NAt and MAt traces.

All vowels revealed the presence of some vibrations on their NAt. This means that during their articulation, some resonances are produced in the nasal cavities, even when the nasal port is closed and there is no flow of air. These vibrations are eliminated when they pass through a low-pass filter, and are, therefore, not apparent on LpNt.

4.5. Conclusions:

The analysis of the traces described in the present investigation, supports the description of nasality in Brazilian Portuguese as presented in Part I of this thesis. The main points are as follows:

a) It has been found that before a nasal consonant, a vowel may be fully nasalized, partially nasalized or not nasalized at all (see Part I, Chapter 2, Section 2.2.).

b) A homorganic nasal consonant does not normally occur following a nasalized vowel and preceding an oral consonant in connected speech. When a homorganic nasal does occur before a stop, it is very short and shows only a very small excursion from the baseline of the nasal traces (see Part I, Chapter 2, Section 2.3.1.(b)).

c) Before pause, and at the end of sentences, the nasal archiphoneme is normally realised as an unreleased nasal (see Part I, Chapter 2, Section 2.3.1. (a)).

d) Following a nasal consonant, a vowel is partially nasalized for the initial half of its duration (see Part I, Chapter 2, Section 2.2.1.).

e) In the sentences investigated, there were only a few cases in which nasal consonants occured in liaison (see Part I, Chapter 2, Section 2.4.).

f) In cases of hiatus, the process of nasalization consistently revealed that the first vowel is predominantly oral and the second vowel is predominantly nasalized (see Part I, Chapter 2, Section 2.1.).

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APPENDIX - 1

In this thesis, all quotations in the text have been given in English, some of them having been translated by the author. In this appendix, all quotations from a language other than English are given in the language in which they were originally found.

(a). "A nasalidade pode acompanhar a emissão da vogal sem continuar além dela: assim são as vogais nasais portuguesas do sul, ã, ẽ, õ, etc., e o diacrítico para as designar é o chamado til (˜); denominam-se também vogais nasais de primeiro grau. Pode, todavia, essa nasalidade acompanhá-las, prolongando-se por guturação além delas: são estas as vogais de segundo grau, que se ouvem no norte do reino, ã, ẽ, õ, e cujo diacrítico pode ser o til dirigido em sentido contrário; o seu efeito acústico lembra os ditongos, e deste modo o ã é quase ãũ, ẽ quase ẽĩ. Assim são as nasais francesas, principalmente as do norte" (G.Viana 1892: 14-15 - see p. 21 of this thesis).

(b). "Dans tous ces mots, les deux voyelles de la diphtongue sont nasalisées et suivies d'un élément consonantique nasal, pour lequel l'air sort uniquement par le nez... On détermine aisément la consonne nasale qui suit la diphtongue au moyen du palais artificiel. C'est une n velaire" (Rousselot 1924: 557 - see p. 34 of this thesis).

(c). "Il ne s'agit pas là d'un timbre fourni par le rhinopharynx et les fosses nasales. En effect, l'étude de sa production montre que la voie nasale est fermée au son par l'accolement du voile du palais à la parois pharyngée postérieure. Ce timbre particulier est considéré à tort comme un nasonnement, alors que sa fourniture acoustique et son mode physiologique sont tout à fait différents. Il s'obtient par la raideur et la fixité des parois du résonateur pharyngobuccal, accompagnées de la formation d'un cul-de-sac par l'un des éléments musculaires hypercontractés de ces parois, la voûte vélopalatine le plus souvent. Pour celui qui sait l'entendre, ce timbre est mi-guttural, mi-nasillé, étant donné que le nasillement correspond à la fermeture presque complète ou totale de la voie nasale" (Tarneaud 1941: 67 - see pp. 113-114 of this thesis).

(d). "Ce fait est bien connu des chanteurs; il a d'ailleurs été signalé pour la première fois par J. et M. Glover qui ont indiqué qu'à partir d'une certaine note aiguë, variable chez les individus, il est impossible de nasaliser un son" (Tarneaud 1941: 69 - see p. 114 of this thesis).

(e). "Des vibrations nasales se rencontrent de même dans les tracés soit de voyelles, soit de consonnes que l'on croirait uniquement buccales. Le fait peut s'expliquer par la propagation du mouvement vibratoire à travers les tissus. Mais il peut être dû aussi à un léger écolement de l'air par le nez, qui est compatible avec la pureté de l'impression auditive: c'est en realité ce qui a lieu" (Rousselot 1924: 526-527 - see p. 143 of this thesis).

(f). "Il se rencontre des dialects où un écolement anormal et assez abondant de l'air par le nez ne produit pas une nasalisation bien appréciable" (Rousselot 1924: 269 - see p. 145 of this thesis).

(g). "Une voyelle nasale est toujours plus ouverte que la voyelle orale correspondante, et dès qu'une voyelle se nasalise, elle tend aussitôt à s'ouvrir" (Straka 1955: 248 - see p. 232 of this thesis).